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INVESTIGATION OF REMOTE SENSING TECHNIQUES AS INPUTS TO OPERATIONAL RESOURCE MANAGEMENT

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PREFACE

This is a Type III draft final report on a resource management study funded through the NASA Landsat follow on activity. The primary objective of the study is to assist participating state agencies to evaluate remote sensing (with emphasis on unmanned resource satellite data) as a cost effective data source in operational programs. Participating South Dakota agencies include: The Black Hills Conservancy Sub-district, the State Planning Bureau, the Game, Fish and Parks Department, and the Department of Natural Resource Development. With the exception of the Sub-district, each agency has committed half a man-year to the project. With NASA high altitude aircraft imagery; low altitude aircraft data, and ground truth information, Landsat data are being evaluated as a data source for such programs as land use mapping, surface water inventories, aspen mapping, and crop identification. Both visual and computerized interpretations are being investigated. Also under investigation is a NASA-developed Digital Image Rectification (DIRS) which rectifies Landsat multispectral scanner digital data using Universal Transverse Mercator coordinates as a grid base. The DIRS package will be evaluated for the potential of improved digital data analysis. Resource data handling is being addressed via MAPCLASS, a program which provides a method of data storage and handling with output via many different methods. Basic project results are discussed and recommendations are made on the operational use of Landsat data for South Dakota State government.

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I. INTRODUCTION

Background

The concept of efficient resource management is receiving increased attention from both local and national organizations. Enacted and proposed legislation has focused considerable emphasis on the desired result of a more orderly use of our limited resources. Since World War II (WWII), considerable investigations by military and civilian aero-space research groups have resulted in the development and refinement of the science of remote sensing. During the past decade, tremendous advancements in remote sensing technology have resulted in the opportunity for application of remotely-sensed data in numerous resource management situations. With the advantages of synoptic view and the potential of sequential coverage on a real-time basis, remote sensing offers the resource manager an unparalleled view of the earth for improved resource management.

Research has been conducted in numerous areas which has resulted in the application of remote sensing to resource management (1, 2, 3, 4). Hydrology, pollution detection, agriculture, and ecosystem analysis (5, 6, 7, 8) investigations have allowed development of the relationship between management requirements and remote sensing data. Satellite-based sensors provide the potential for timely input in a variety of regional applications from a vantage point that is both new and valuable to today's resource managers.

The need for comprehensive resource management is well recognized. The fact that some current ground-oriented inventory and planning techniques are costly, laborious, and too time consuming to be of maximum value is becoming increasingly evident. Remote sensing techniques which could provide cost-effective and timely data must be investigated for potential use by state and local government. This study was designed to introduce remote sensing to and provide basic inputs for state agencies responsible for planning, coordinating, and regulating the protection and development of South Dakota's natural resources.

Objectives

This pilot study was directed toward initiating the development of remote sensing inputs to operational South Dakota natural resource management problems. The complexity of resource management requires that timely, reliable information be available. The thesis is that remote sensing can provide inputs to improve decisions pertaining to resource policy development and program management.

Present ground-based data collection methods do not provide many state agencies with the current sequential natural resource information required for sound management. In this pilot study, three South Dakota governmental agencies evaluated the cost-effectiveness and reliability of remote sensing inputs versus the present methods of obtaining policy-making and management information. The South Dakota State Planning Bureau evaluated land use inventory data for the purpose of a statewide land use inventory program. The South Dakota Department of Game, Fish and Parks utilized remote sensing data to assist in forestry, range, and fisheries management. The Division of Resource Management of the South Dakota Department of Natural Resources Development evaluated remote sensing inputs for statewide water resources planning. The Black Hills Conservancy Subdistrict provided assistance in coordinating the study site activities and in evaluating progress and results. The Remote Sensing Institute developed and provided necessary remote sensing information products and interpretive assistance to the state agencies.

The specific objective of this effort can be summarized as follows:

1. To investigate the utilization of remote sensing data for operational natural resource management in the Belle Fourche River Basin of South Dakota;
2. To develop basic resource thematic maps from satellite, high altitude, and low altitude aircraft data;
3. To evaluate cost-effectiveness of remote sensing data for use by South Dakota state operational agencies; and

4. To make recommendations on operational systems utilizing remote sensing data for natural resources management.

Participating Organizations

Among the goals of the South Dakota Department of Game, Fish and Parks (GF&P) are: (1) to maintain the optimum population and sustained yield of game animals and other wildlife compatible with available habitat, (2) to enhance forested lands and tree related resources for the benefits of soil and water conservation, wood products production, wildlife and scenic beauty, and (3) to take into account all aspects of the public interest in fish and wildlife, forests and parks, according to a comprehensive plan.

Certain issues related to these general goals have surfaced and are in need of attention. Among these are: (1) overstocked timber stands in the Black Hills, a) now experiencing a mountain pine beetle epidemic, b) posing a wild fire threat, and c) adversely affecting the amount of precipitation reaching the ground; (2) the irretrievable loss of quality fish and wildlife habitat due to expanding agricultural, industrial, and domestic uses of South Dakota resources.

The importance of these problems to the public is recognized in state law by directing GF&P to regulate, direct, and control the conservation and protection ... of all fish and wildlife; and to engage in forest and rangeland management and protection.

Plants and animals are dependent upon certain types of habitat for food and shelter. The Department is seeking improved methods for inventorying habitat to determine changes in plant and animal population resulting from man's activities. This investigation has focused on the use of remotely-sensed data as a tool with which to pursue certain GF&P goals.

The South Dakota Department of Natural Resources Development (DNRD) has the responsibility to develop the State Water Plan and to enforce the water use regulations of the state. The basic concept is to develop the resource capabilities that exist in South Dakota. As part of the State Water Plan, DNRD has designated 16 sub-basins

in the State. These sub-basins are river basins that rely upon similar sources of water and have basically the same water utilization problems.

Resource inventories are being prepared for each river basin in the state. These resource inventories include: (1) physical environment and land capability, (2) hydrology, and (3) water use development and potential. Secondary data contained in existing reports along with other information found in the files of state agencies are being used to develop the resource inventories. The purpose of the inventories is to provide basic information regarding the capability and availability of the physical resources in all 16 river basins of the State. Information typically collected includes data on land use, soils, minerals, wildlife, recreational areas, and hydrology.

DNRD is attempting to obtain current information on physical resources throughout the state. In determining resource capability, DNRD is relying upon Conservation Needs Inventory (CNI), Crop and Livestock Reporting Service Reports, Soil Surveys, and other pertinent publications. Often such information is not provided by river basin but rather by political boundaries. This inherently creates errors when the data are subdivided to provide information on river basins. In many cases, the information may not be current and samples are not considered adequate or representative of the river basin. An effort is being made to inventory all surface waters in each basin, but such estimates are difficult as certain ponds and lakes may be dry or no longer exist. Therefore, timely and sequential information is extremely desirable for management and development.

A legislative directive calls for updating the State Water Plan every four years. In addition, as projects are proposed for implementation, increased information on specific areas will be required. This pilot study has provided the opportunity for the Department of Natural Resources Development to utilize remote sensing techniques

in these operational programs.

The State Planning Bureau (SPB) is currently developing a statewide land use inventory system. Initially, the inventory includes a Level I land use classification (Anderson, et al 1976), compiled from visual interpretation of Landsat data. The final step includes a Level II, partial Level III, Anderson classification, compiled from computer processing of digital Landsat data. The primary objective of this inventory system is to improve the natural resource information base to aid SPB in providing technical assistance to local governments, particularly in the area of land use planning and zoning. It is also anticipated that the expanded information base will be used by state government departments and agencies concerned with resource and land use policy decisions. The structure of the information system and analytical capability developed by this pilot study, and the ongoing state-wide inventory project, will be designed to evaluate the usefulness of remote sensing information in meeting the needs of state and local government agencies for technical assistance.

In addition, SPB has responsibilities to aid in the process of determining the criteria necessary for identifying and delineating areas of critical state concern. Basic to this determination is the Level I land use inventory. In addition, more detailed descriptions of land use are required. It is anticipated that these will conform closely to the Level II classification.

Each of the three participating state agencies committed one-half of a man-year of labor to the project. The Department of Game, Fish and Parks assigned five people to become actively engaged in the project. The Department of Natural Resources Development and the State Planning Bureau each named two people as participants. GF&P representatives included fisheries, wildlife, and forestry-oriented specialists. DNRD personnel were trained in water resources and SPB representatives were specialists in computer processing of natural resources information. The Black Hills Conservancy Subdistrict (BHCS) actively assisted in local test site coordination, review of data

products, and coordination of reporting efforts.

Study Site

The Belle Fourche River Basin in western South Dakota (Figure 1) was selected as the study area for state agencies to evaluate the application of remote sensing. The Belle Fourche Basin was selected because of its relatively small size and diversity in natural resources management problems. Land use within the test site region includes agriculture, recreation, lumbering, tourism, mining, residential, and industrial development. The diversified land use is the result of the test site area being comprised of forest, rangeland, cropland (irrigated and dryland), fresh water, and urban areas. The techniques developed are deemed applicable to other river basins within the state.

II. DATA COLLECTION

Intensive Study Site Locations

Areas of specific interest in terms of physical location and study parameters were specified by priority by each of the participating agencies during the planning stages of the project. Applicability of remotely-sensed information was not a criteria in determining study parameters since, in general, agency personnel were very experienced in the use of remotely-sensed data. The individual lists were then compiled to form a master list from which the final site plans were made.

Intensive site locations were positioned in seven areas within the Basin (Figure 1). Specified sites were those areas where ground truth measurements were to be collected and low altitude aircraft data collection was scheduled in addition to high altitude aircraft and Landsat coverage. Table 1 reviews the agencies' requirements for each site.

It should be reiterated that both site selection and topical study areas were determined by the agencies involved. In this way, input to operational situations could be tested in accordance with data applicability.

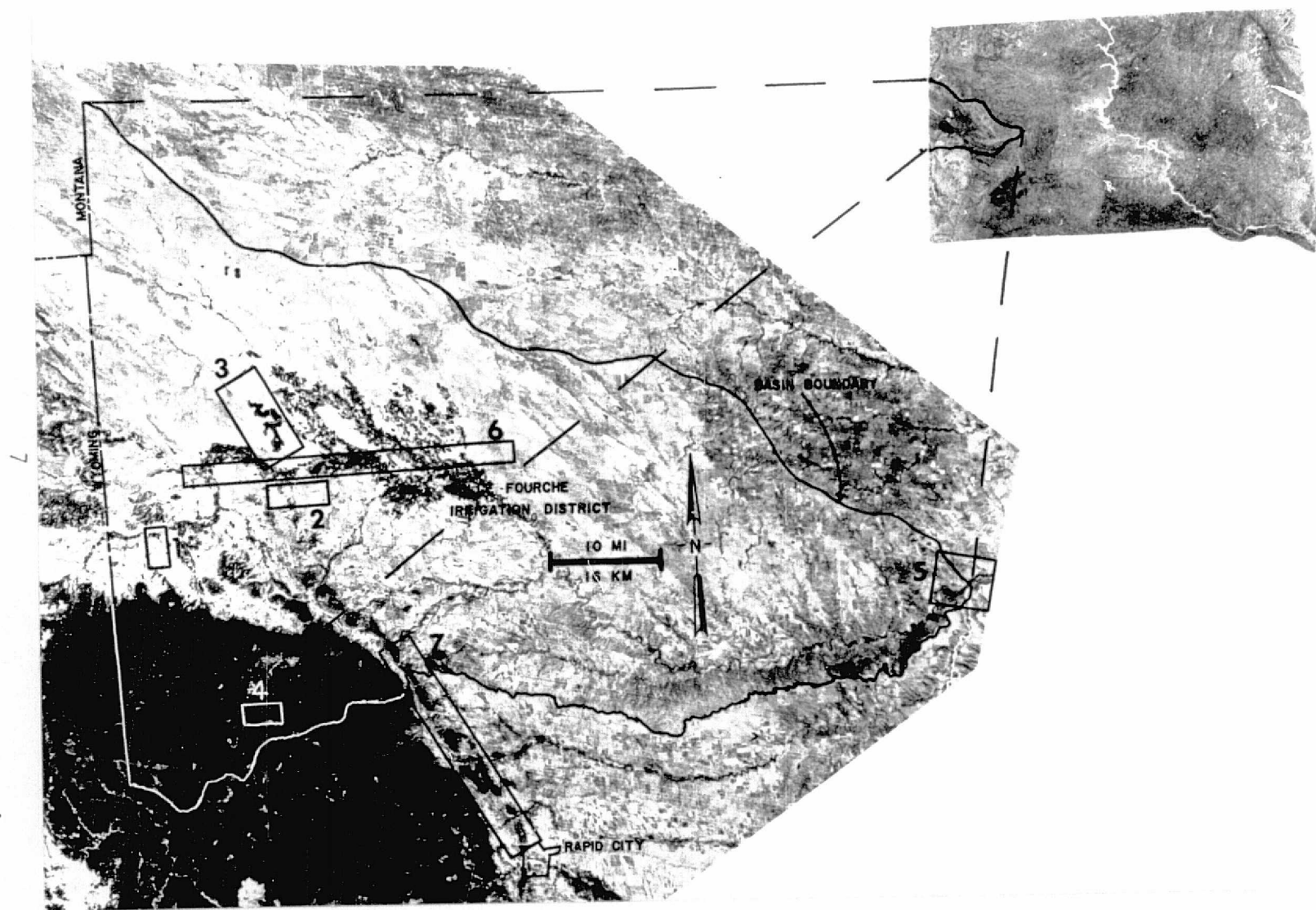


Figure 1. Location of the Belle Fourche River Basin and intensive study sites.

TABLE 1. AGENCY AND STUDY PARAMETERS.

Test Site No.	Parameters to be studied	Agencies Involved*		
		DNRD	SPB	GF&P
1	Water Quality Surface Water Area Land Use	X X	X X	
2	Irrigation Canal Seepage Irrigation Delineation	X X		
3	Water Quality			X
4	Water Quality Surface Water Area Forestry Typing Mt. Pine Beetle Activity	X X		X X
5	Ranchland Use, Pasture Stocking Rates Water Quality			X X
6	Irrigation Delineation Land Use Soil Association Crop Identification Grouse Dancing Grounds Water Quality & Area Vegetation	X X	X X X	X X X
7	Land Use		X	

* Department of Natural Resource Development (DNRD)
State Planning Bureau (SPB)
Department of Game, Fish and Parks (GF&P)

Site 1 is an area along Spearfish Creek and the Redwater River bounded primarily by a combination of irrigated and dryland farming. Stockdams in the area provided potential sites for surface water studies. Area number 2 contains irrigation canals within the Belle Fourche Irrigation District. Leaks in the canal system provided the opportunity to evaluate remote sensing for the detection of these leaks. Irrigated cropland along the canal contribute to the data available for delineation of irrigated areas. Site 3, the Belle Fourche Reservoir, is located behind Orman Dam which, when built, was one of the largest earthen dams in the world. The Reservoir itself is relatively shallow and the water is used primarily for irrigation within the district. Secondary uses include water based recreation and livestock watering. Study area 4 was the only planned site solely within the Black Hills and was selected because of the Mountain Pine Beetle activity in the area. The confluence of the Cheyenne and Belle Fourche Rivers provide the location for site 5. The area north of the confluence was under consideration by the U.S. Army Corps of Engineers as potential mitigation area for land inundated by construction of the main-stem reservoirs along the Missouri River within South Dakota. A resource survey of the area was required for preparation of suggested development plans for the area. One of the longest sites, number 6, stretches from about 16 km (10 miles) east of Newell (into rangeland) to Belle Fourche. Large areas of cropland are covered as are numerous surface water bodies. The last site, number 7, extends from Sturgis to Rapid City. The area along Interstate 90 is of specific concern to planning officials because of the intensive residential development in the areas adjacent to the Black Hills area.

With sites and study topics selected, data collection was addressed by various state agencies.

Data Collection

Participating state departments expressed a desire to obtain data during time periods which would reflect a variety of seasonal surface conditions within the river basin. Based on discussions with the agencies, late spring, mid-summer, and early fall were considered as providing the optimum temporal changes. Agencies mutually scheduled total high altitude coverage of the basin during the first 15 days in June and the last 15 days in September. RSI flights were scheduled for the first 15 days in June and August and the last 15 days in September. These sources of data, in conjunction with ground truth and Landsat data would provide the basis for observing the changing ground conditions as they are recorded by multi-stage remote sensing platforms.

A standing Landsat order was placed with EROS to obtain data from 26 Landsat passes. Actual remote sensing data sensors employed during this effort are summarized in Table 2 and data collected are listed in Table 3. Minimum requirements for imagery received were quality of five and 80% cloud cover. High altitude data for some of the pre-designated test sites could not be used because of cloud cover. In those instances extensive ground truth was collected.

Data Analysis

Remote Sensing Institute facilities and equipment were available for use by state agencies during this project. A listing of RSI equipment is found in the Appendix. Certain instruments were used extensively throughout this effort and are listed in Table 4.

III. APPLICATIONS AND RESULTS

Land Use

All participating state agencies expressed interest in evaluating various land use data sources. GF&P and DNRD are under legislative mandate to provide resource inventories of each of the 16 river basins in the state every four years. One of the most important resources in South Dakota is the land itself. Detailed information regarding the

TABLE 2. REMOTE SENSING SENSORS AS EMPLOYED.

Collection Device	Sensing Medium	Filter or Spectral Range	Platform
Multi-Spectral Scanner MSS 4	optical/electronic	.5-.6 μm	Landsat
MSS 5	optical/electronic	.6-.7 μm	Landsat
MSS 6	optical/electronic	.7-.8 μm	Landsat
MSS 7	optical/electronic	.8-1.1 μm	Landsat
12" Zeiss	Film #2443	15	RB-57
6" RC-8	Film #S0-397	2E	RB-57
80 mm Hasselblad	Film #2424	87B	RB-57
80 mm Hasselblad	Film #2424	89B	RB-57
80 mm Hasselblad	Film #2402	25	RB-57
80 mm Hasselblad	Film #2402	58	RB-57
6" RC-8	Film #S0-397	2E	U-2
80 mm Hasselblad	Film #2402	58	U-2
80 mm Hasselblad	Film #2402	25	U-2
80 mm Hasselblad	Film #2424	87B	U-2
80 mm Hasselblad	Film #2424	89B	U-2
Hasselblad	Film #2443	15/10m	Beechcraft RC45J
Hasselblad	Film #2448	HF3+4	Beechcraft RC45J
Hasselblad	Film #2402	25	Beechcraft RC45J
Hasselblad	Film #2402	58	Beechcraft RC45J
Daedalus Thermal Scanner	optical/electronic	8.7-11.5 μm	Beechcraft RC45J

TABLE 3. REMOTE SENSING DATA AS COLLECTED

Area	Date	Platform	Altitude (AGL)
Entire Basin	every 9 days	Landsat	917 km (570 mi)
Entire Basin	June 25, 1975	RB-57	15,240 m (50,000')
Intensive Study Sites	June 27, 1975	Beechcraft	all 3050 m (10,000') except site 2
Entire Basin	Sept. 13, 1975	U-2	18,300 m (60,000')
Intensive Study Sites	Sept. 23, 1975	Beechcraft	2320 m (7,600')
Intensive Study Sites	Sept. 24, 1975	Beechcraft	3050 m (10,000')

TABLE 4. EQUIPMENT USED.

Type of Equipment	Manufacturer	
Zoom Transfer Scope Projection Table	Bausch & Lomb	Overlay photos and maps Reduce/enlarge photos & drawings
Light Table	Bausch & Lomb	Film viewing, interpretation
Stereoscope	Bausch & Lomb	Stereo viewing of 70 mm film
Computer System	IBM 370-145	Digital analysis, data handling, mapping
Photographic Enlarger	Durst	Color enlargement of prints
Photographic Enlarger	Durst	B&W enlargements prints

use and the spatial distribution of the various land uses is considered a significant input for these four-year surveys. SPB is preparing a land use map of the state using digital analysis of Landsat MSS CCT data. SPB is interested in evaluating the digital analyses in relation to results obtained from other data sources.

Historically, land use information has been obtained from a variety of sources including the Conservation Needs Inventory and Crop and Livestock Reporting Service Reports. Usually such tabular data are not subdivided into river basins but into political subdivisions such as counties. This procedure results in estimating errors as the data are subdivided to a river basin status.

Level I land use information was initially interpreted for the entire 824,000 hectare (2,060,000 acres) Belle Fourche River Basin using 1:250,000 27 July Landsat color composite and MSS 7 imagery. Initially, forest cover was interpreted from 1973 winter imagery. A winter snow-covered scene was selected for interpretation of coniferous forest because of the distinct boundaries between snow covered areas and the non-snow covered tree canopy. Agricultural land was interpreted from the color composite and surface water from MSS 7 prints. RSI provided prints to GF&P and DNRD personnel for an initial interpretation of Landsat data. Conservation Needs Inventory data were obtained for Lawrence, Butte, and Meade Counties (9), the three counties comprising the Basin. Land use acreage estimates were made by determining the percentage of each county within the Basin and multiplying this figure by the respective CNI land use statistics for each county. The estimates were made assuming the distribution of land use was similar throughout the county. These Level I land use data are listed in Table 5.

Because of the eight-year difference in data and the fact that CNI statistics are based on a random sample rate of two percent rather than areal coverage, as Landsat data, no direct conclusions regarding data accuracies can be made between the Landsat and CNI information. However, as long as there is a trend of rangeland being converted to

TABLE 5. LEVEL I LAND USE FOR BELLE FOURCHE RIVER BASIN.

Land use	Percent Classified (hectares)			
	RSI Landsat (1973,1975)	DNRD Landsat (1973,1975)	GF&P Landsat (1973,1975)	CNI (1967)
Range	68 (560,400)	75 (618,000)	72 (593,300)	77 (634,500)
Agricultural	18 (148,400)	11 (90,700)	17 (140,100)	14 (115,400)
Forest	13 (107,100)	13 (107,100)	11 (90,700)	7 (57,700)
Urban	.3 (2,500)	.3 (2,500)	.3 (2,500)	--
Surface Water	.3 (2,500)	.3 (2,500)	.3 (2,500)	--
Other	--	--	--	.8 (6,600)

agricultural production, it seems feasible to expect an increase in agricultural land and a corresponding reduction in rangeland during the eight years separating the data sources. This increase is reflected in the RSI and GF&P interpretations. The basic advantage of Landsat data over CNI-type statistics is seen in Figures 2 and 3. The spatial location of the various Landsat-interpreted land use categories is apparent in this mapform, whereas CNI-type data produce only the statistics (Table 5).

Available Landsat imagery was reviewed to select optimum interpretation scales and imagery dates which would provide the highest overall classification accuracies. A particular area, ten townships comprising 93,279 hectares (230,492 acres), was selected for study. Unfortunately, the area containing the most Landsat imagery was not located in one of the areas over which low altitude imagery was collected.

The site seen in Figure 4 is located north and east of Sturgis in the center of the basin. Two dates of high altitude coverage were available for the site. Landsat data for each of the months May through November were also available.

Interpretation of high altitude color infrared transparencies produced the agricultural percentages listed in Table 6. The "apparent" five percent decrease in agricultural land during the three months separating the data is reflective of fluctuation in vegetative conditions of pasture land and rangeland. The Anderson land use classifications include pasture as a subcategory of agricultural land with rangeland as a major category in itself (10). In certain areas in the June data, pasture land appears similar to other agricultural fields and is easily distinguished from rangeland. Fenced pasture lands are also distinctive from the surrounding apparently less profusely vegetated rangeland due to different management and tame pasture versus rangeland. Because the season progresses, the grassy vegetative cover reaches senescence and tends to turn brown and dry. There is an increase in visible reflectance due to the decrease in chlorophyll.

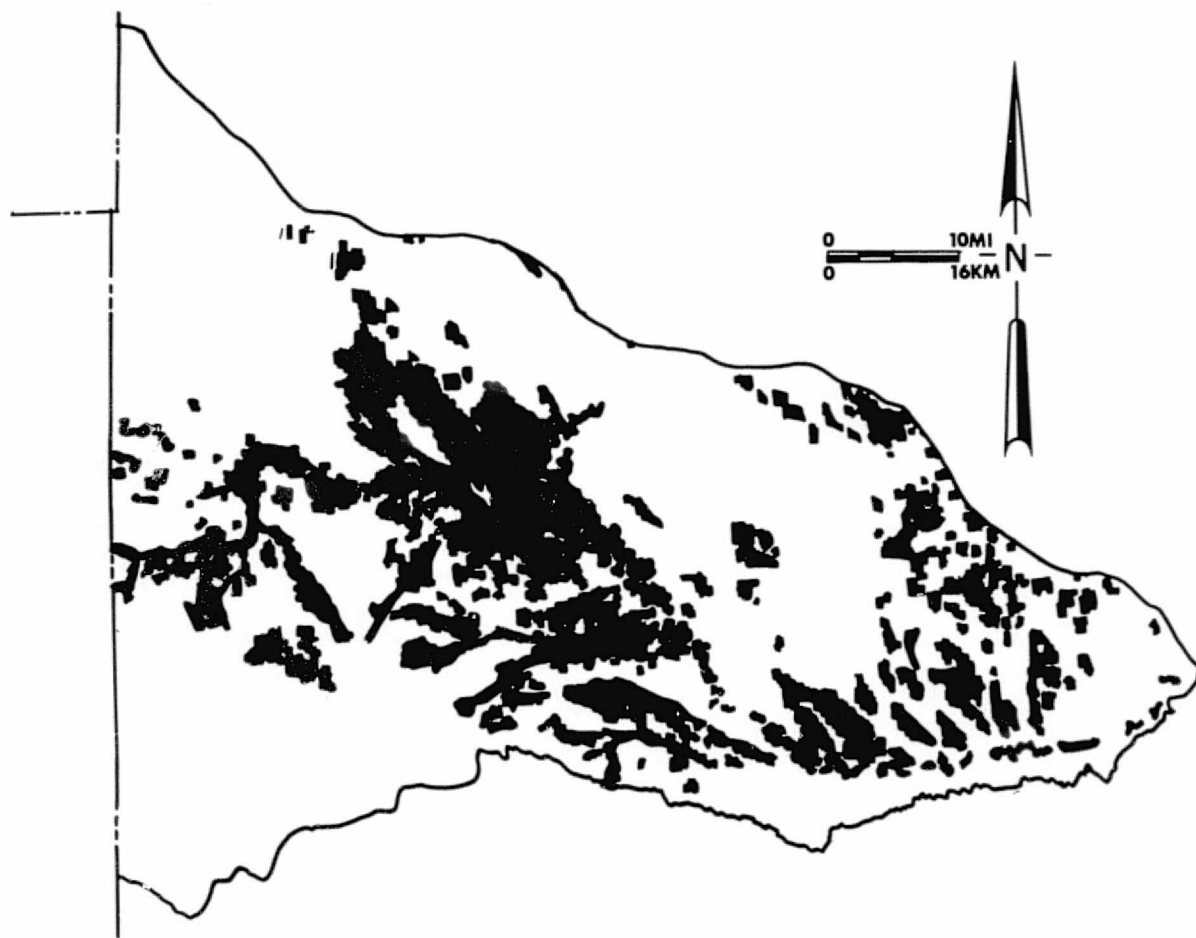


Figure 2. Agricultural land in the Belle Fourche River Basin as interpreted from 27 July 75 1:250,000 Landsat color composite imagery.

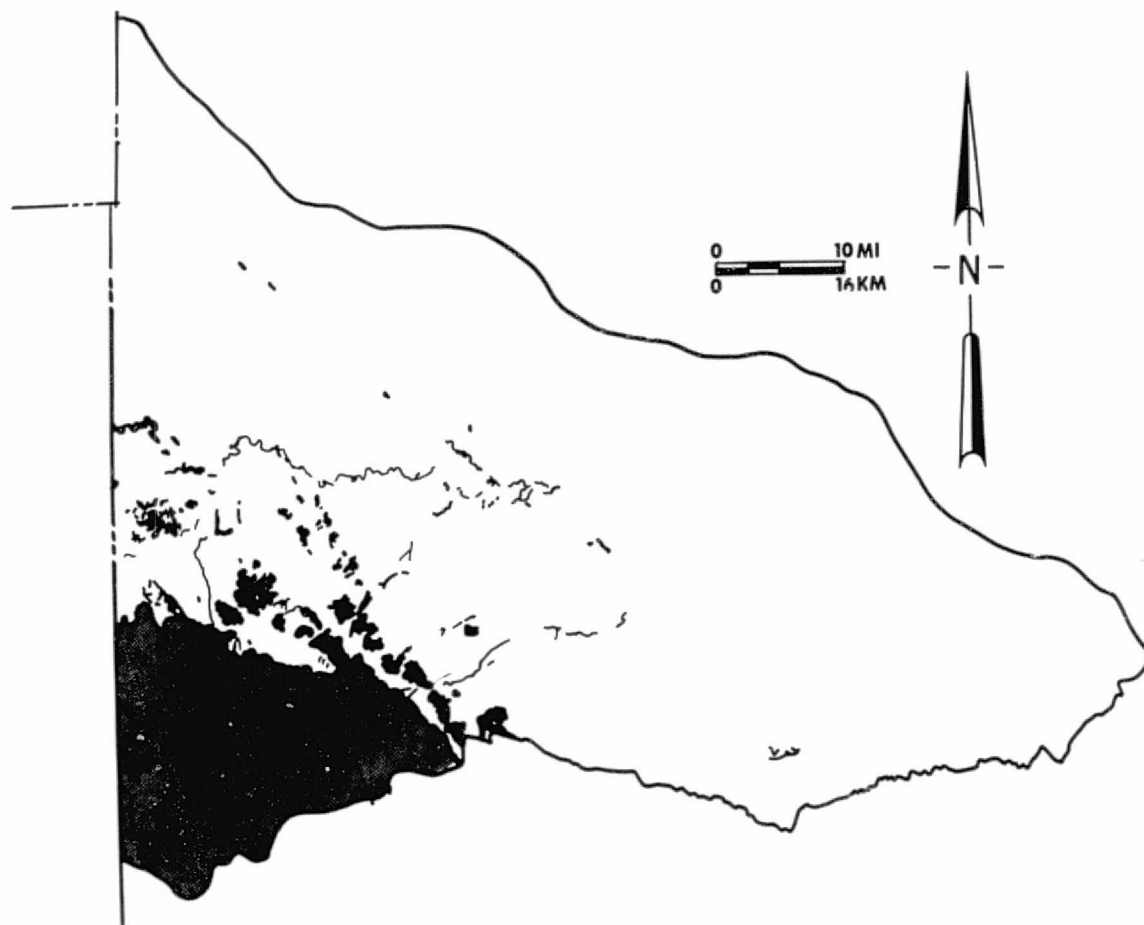


Figure 3. Forested land within the Belle Fourche River Basin as interpreted from 1973 winter Landsat imagery. Dark areas within the shaded (forested) area are non-forested. Dark areas outside the shaded area are forested.

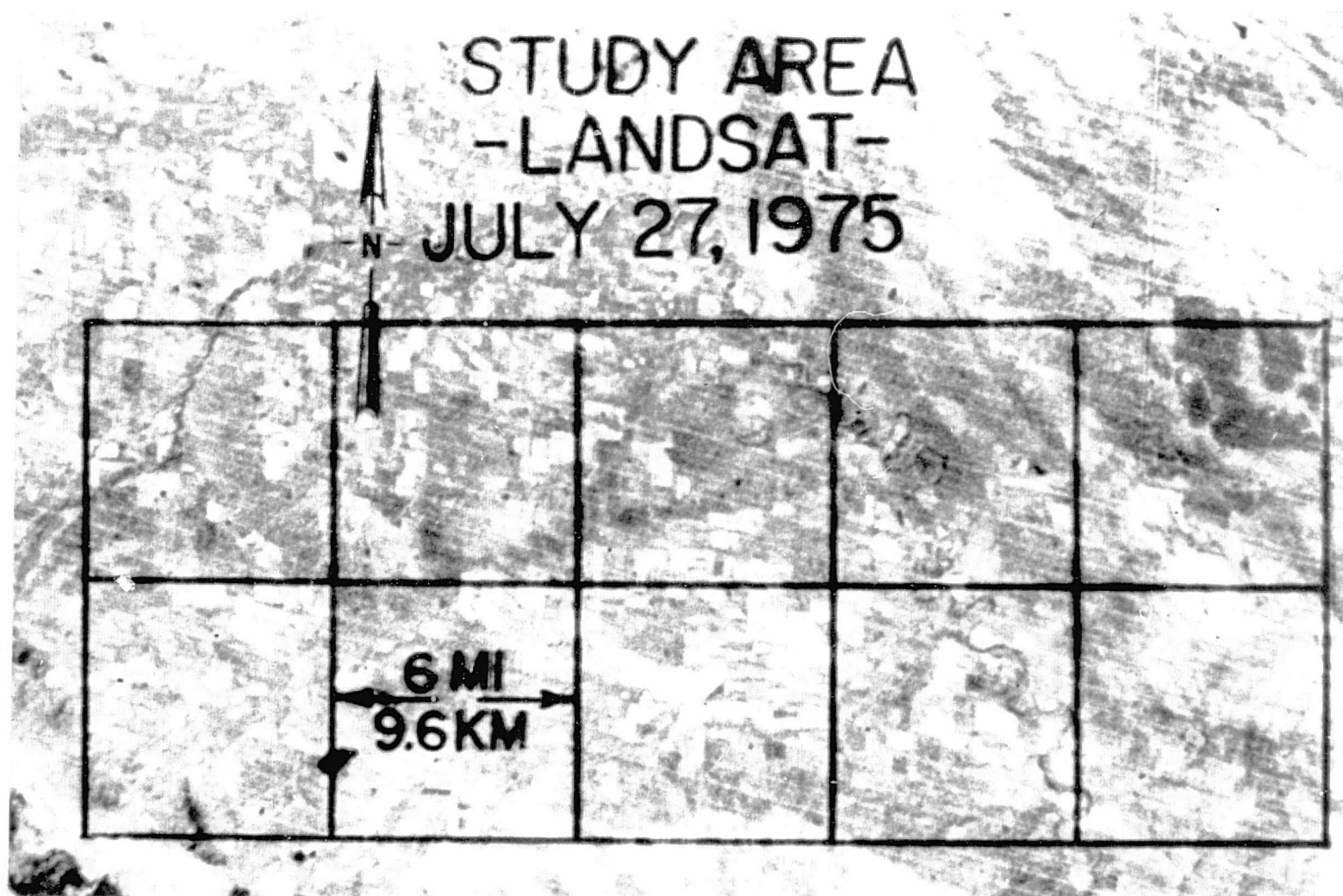


Figure 4. Ten-township test site used in land use and surface water mapping. Black and white print of color Landsat MSS scene ID 2186-17004.

Thus, previous differences between pasture and range are now masked by the integration of visible and infrared responses. For interpretation of Level I agricultural land use in Western South Dakota, the distinction between pasture and rangeland is easier using data from early growing season instead of data collected during the latter months of the growing season. September and June high altitude imagery results are compared in Table 7. These results suggest that the 24 percent agricultural land classified as rangeland from the September interpretation is a result of reflectance changes as the season progresses.

TABLE 6. HIGH ALTITUDE AIRCRAFT INTERPRETATION

Data Source	Date	Scale Interpreted	Percent Agricultural Land
High-altitude Color IR	25 Jun 75	1:114,506	27
High-altitude Color IR	23 Sep 75	1:125,880	22

There are a number of interpretive guides used to assist in classifying land into the agricultural category from high altitude imagery. Tone, texture, and pattern are used primarily but recognition of detailed information such as haystacks, cutting and cultivating patterns, etc., is also helpful. In the June interpretation, these interpretive techniques could be employed. By September, tonal differences were reduced substantially and the interpretation was based on other indicators. Certain pastures in particular were unidentifiable without the color differentiation present in the June imagery. As Landsat interpretations must rely solely on the tonal/pattern signatures, it is reasonable to expect more misclassification of agricultural land as rangeland (later confirmed) as the season progresses. It is important then to obtain ground truth (i.e., aerial photography) which coincides with the date of satellite data. The June high altitude interpretation for the ten-township area is deemed

TABLE 7. COMPARISON OF SEPTEMBER HIGH ALTITUDE AIRCRAFT DATA WITH JUNE HIGH ALTITUDE AIRCRAFT DATA.

Percent of agricultural land: Interpreted as agricultural land using September data.	Percent of agricultural land: Interpreted as rangeland using September data (possible pasture land).	Percent of rangeland: Interpreted as rangeland using September data.	Percent of rangeland: Interpreted as agricultural land using September data.*
76.4	23.6	97.1	2.9

8 *Includes 720 acres of new agricultural land as rangeland interpreted as agricultural.

the more accurate of the two high altitude aircraft interpretations for use in immediate interpretive comparisons.

Before any recommendations regarding the potential use of Landsat imagery could be offered, four basic questions required answering. They are: 1) What method of interpretation is to be used? 2) At what scale will interpretations be conducted? 3) What is the optimum Landsat time "window" for Level I land use? and 4) What are expected classification accuracies?

Landsat data can be interpreted in two major ways: visual and digital. Within the visual interpretation, the data can be extracted from transparencies or prints. Visual interpretation of 1:1,000,000 Landsat color composite transparencies generally requires magnification to allow extraction of desired detail. Initial interpretations were conducted using the Bausch and Lomb Zoom Transfer Scope (ZTS) and a 27 July 1975 Landsat color composite generated by the EROS data center. ZTS interpretation data can be found in Table 8. For comparative purposes, only the agricultural land percentages are shown since this area is primarily either agricultural land or rangeland. The ZTS interpretations were time-consuming because of the time required to register the image to a base map. At 1:250,000, four townships can be viewed through the scope. For the 130-township river basin, approximately thirty registrations would be required. Another difficulty encountered using Landsat data interpreted from the ZTS system is spatial accuracy. As interpretations approached the edges of the field of view and then were re-registered to the next area, adjoining interpretation lines did not consistently align with one another. Errors at these match lines were consistently between .4 and .8 scale kilometers (.25-.5 miles). This specific problem was reduced somewhat at the larger 1:125,000 scale; but instead of interpreting four townships in a single registration set-up, only one township could be comfortably seen through the ZTS field of view. Therefore, 130 separate registrations would be required to interpret the area under consideration. Also, at the 1:125,000 scale there

was a problem of registering MSS data to base maps. For certain sections of Western South Dakota, there are areas where no map-related landmarks are visible in a Landsat image for the ZTS field of view. These areas make accurate registration of a single township difficult and time-consuming. Based on these experiences, use of the ZTS-Landsat transparency combination is not recommended as a sole device to assist in the interpretation of Landsat data.

TABLE 8. ZTS INTERPRETATIONS OF LANDSAT FOR TEN-TOWNSHIP AREA.*

Data Source	Date	Scale Interpreted	Percent Agricultural Land
Landsat Color Composite	27 July 75	1:250,000	34
Landsat Color Composite	27 July 75	1:125,000	35

*This area is primarily agriculture and rangeland (small amounts of water).

The importance of scale was determined by interpreting data from two prints of decidedly different scales. Accuracies are reported in Table 9. Accuracy increased with the larger prints. Reproductions of the interpretations and the ground truth interpretation are found in Figures 5, 6, and 7. In Figure 5 the ground truth, area A, is a strip of rangeland within an agricultural area. Area B is intermittently spaced agricultural land along the Belle Fourche River. Little difficulty was encountered (Figure 6) in interpreting the major agricultural areas at 1:125,000. However, some detailed information was lost. The rangeland at A was included as agricultural land and the small fields surrounding B were grouped into fewer, larger agricultural areas. An interpretation of the 1:125,000 color print is shown in Figure 7. Rangeland at A is correctly identified and the field groupings at B have not been aggregated into larger

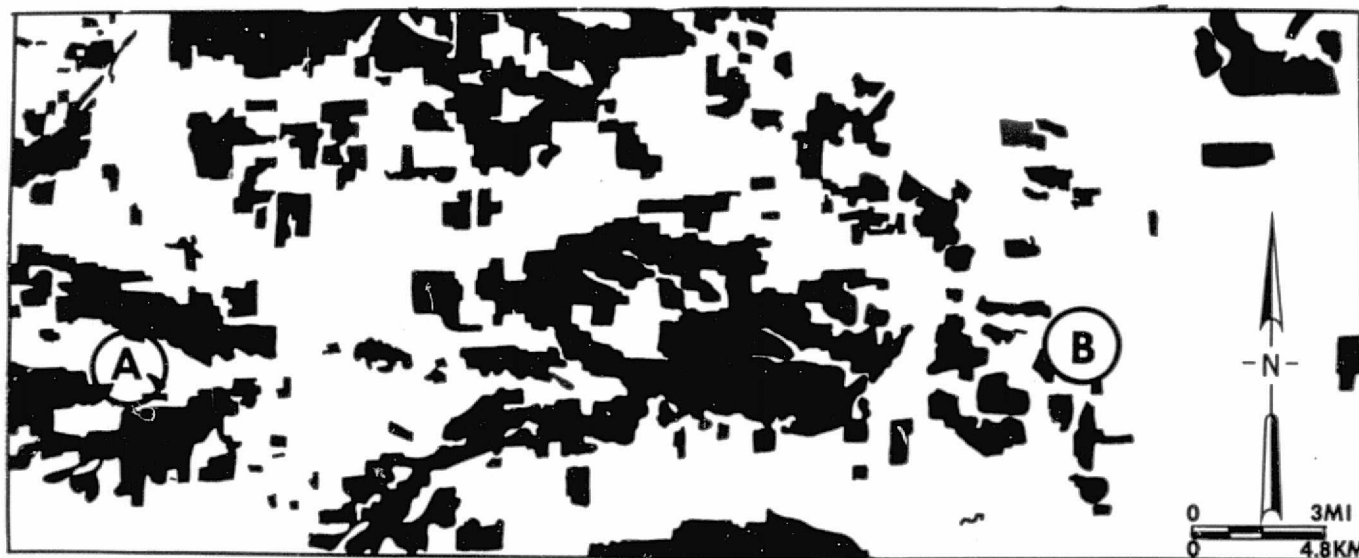


Figure 5. June 1975 high altitude aircraft color infrared transparency interpretation of agricultural land for the ten-township test area as pictured in Figure 4. Area "A" is rangeland passing through an agricultural area; area "B" is intermittently spaced agricultural land along the Belle Fourche River. Interpretation scale: 1:115,000.



Figure 6. Agricultural land interpreted from a 27 July 75 Landsat color composite transparency. Image was registered to 1:250,000 base map using a Zoom Transfer Scope. Detailed information is not consistently interpreted. Rangeland at "A" was included as agricultural land and the small fields surrounding "B" were grouped into fewer, larger agricultural areas.



Figure 7. Agricultural land interpretation of a 1:125,000 27 July 75 Landsat color composite print. Rangeland at "A" is identified and the field groupings at "B" have not been coalesced into larger units to the extent of the 1:250,000 interpretations of Figure 6.

units as they appear at the 1:250,000 scale.

TABLE 9. INTERPRETATION OF 27 JULY 1975 PRINTS AT TWO DIFFERENT SCALES.

Interpreter	Scale of print	A/A %*	R/A %**
1	1:125,000	67	12
1	1:250,000	60	18
2	1:125,000	83	10
2	1:250,000	65	13
3	1:125,000	84	16
3	1:250,000	71	17

*A/A: Percent of June RB-57 agricultural land interpreted as agriculture from Landsat.

**R/A: Percent of June RB-57 rangeland interpreted as agriculture from Landsat.

Landsat data for May through November were interpreted and the spatial accuracy of the Landsat interpretations (as compared to June high altitude aircraft data) were calculated. Table 10 contains the accuracy information for those interpretations which had the highest percent accuracy for agricultural land for each date of imagery interpreted. Rangeland was correctly interpreted 90 percent of the time, irrespective of season. Interpretations of agricultural land are more dependent on imagery taken in a particular season. Data in Table 10 indicates that a prime date for interpreting agricultural land from Landsat for Western South Dakota is in the mid May to July growing seasons.

TABLE 10. LANDSAT INTERPRETATION BREAKDOWN (as compared to RB-57 "ground truth") FOR BEST DATA IN EVERY MONTH EVALUATED FOR SPATIAL ACCURACY.

PERCENT					
Date	Ag. Land as Ag. Land	Ag. Land as Range	Range as Range	Range as Ag.	Avg. Accuracy $\frac{[A/A+R/R]}{2}$
24 May	84	16	84	16	84
12 June	84	16	94	6	89
27 July	84	16	91	9	88
5 Aug.	73	27	92	8	83
1 Sep.	68	32	89	11	79
25 Oct.	40	60	96	4	68
12 Nov.	52	48	93	7	73

A crop calendar for the Belle Fourche Basin (Figure 8) shows the mid May to July period intersects most crops in Landsat-recognizable stages of development. Small grains are heading and ripening and are identifiable as red or yellow patterns respectively on a color composite. Corn and sorghum can be identified as either bare fields (shortly after planting) or as bright red colors as the plants grow and mature. Alfalfa is identified by a very bright red signature. Wild hay areas, which for this interpretation were considered agricultural, can be interpreted only after cutting and then as a pattern within the predominantly range areas.

Individual bands of black and white Landsat transparencies are less expensive than a color composite and black and white prints are less costly than color. To evaluate the use of individual bands of Landsat data for land use data, an area was chosen for interpretation which had already been interpreted using color prints. MSS 5 and 7

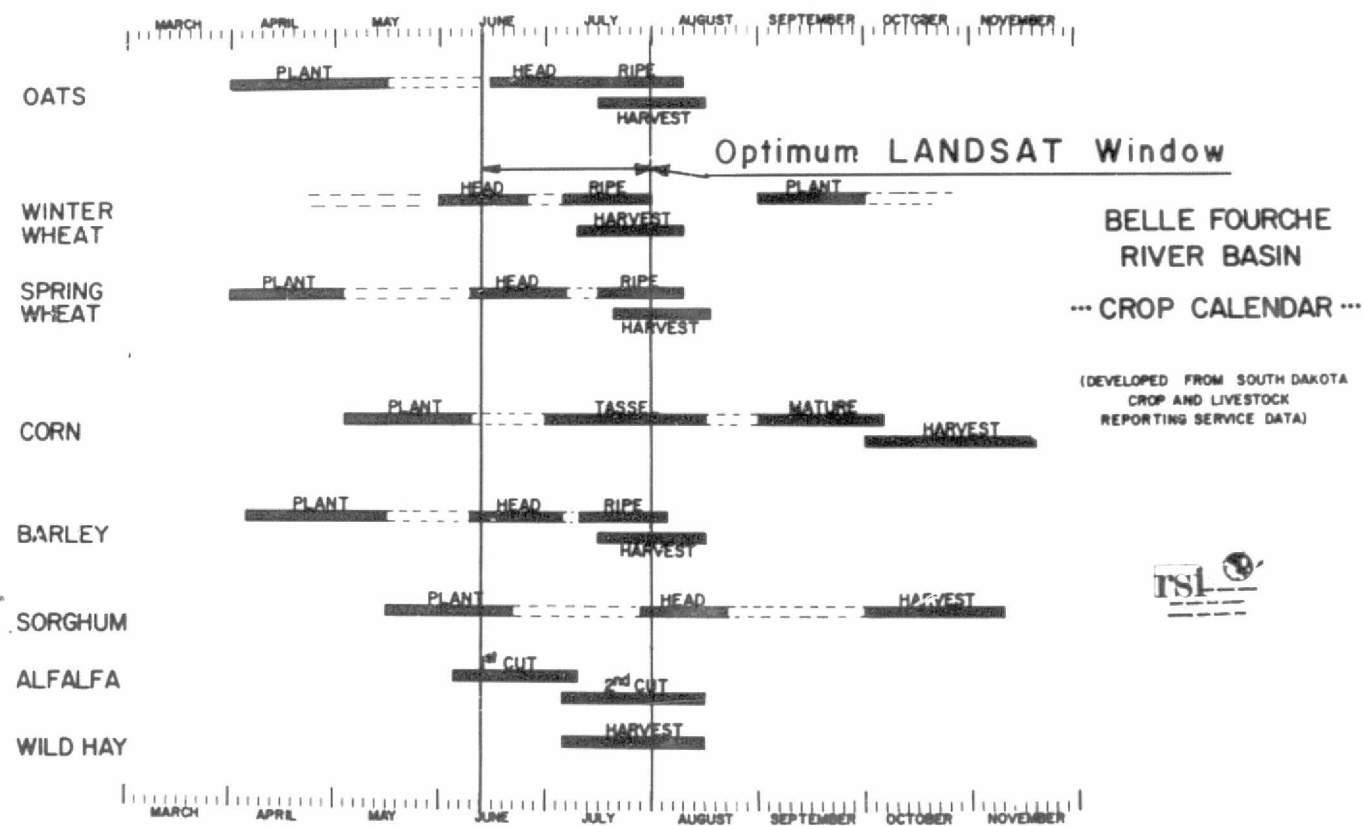


Figure 8. Crop calendar for the Belle Fourche River Basin with optimum Landsat Level I land use window indicated.

were selected because of their inherent benefits in detecting vegetation (i.e. MSS 5 is filtered red and MSS 7 is near infrared). Data are found in Table 11. Certain vegetated agricultural areas were not easily recognizable on single bands of MSS 5 and 7. The overlay procedure was biased toward agricultural land. That is, if agricultural land was interpreted on either MSS 5 or 7 or both, it was outlined on the new interpretation. However, rangeland was only included on the new map if it were present on both MSS 5 and 7 interpretations.

The combined July MSS 5 and 7 data produced optimum classification percentages although still somewhat less than the May, June, and July color composite interpretations as listed in Table 10.

The State Planning Bureau (SPB) is currently using Landsat digital data and the Landsat Imagery Analysis Package (LIMAP) software to produce a state-wide land use inventory. June 1973 data are being used for the western quarter of South Dakota. The basic areal unit of the SPB analysis is the county. Butte County was used as a test area for digital analysis as most of the county is in the Belle Fourche Basin.

To begin the analysis of the county, the data were rectified to remove the angular distortion in the north-south and east-west directions. This was done using a nearest neighbor rotation method. The amount of distortion in an image can be estimated by measuring the slope of lines on the image which are straight north-south and east-west lines on the ground (usually roads or section lines). This calculation and correction must be done for both directions since the distortion is different. Once the analysis area was rectified, it was mapped using a gray tone line printer technique. The rectification procedure used in LIMAP can best be described as an oblique rotation to approximate north-south orientation.

After the data are rectified and printed, training fields are selected to "train" the computer in classifying the land uses. The

TABLE 11. PERCENTAGE INTERPRETATION BREAKDOWN (as compared to RB-57 interpreted "ground truth" data) FOR B&W LANDSAT DATA.

Data Source	Percent				
	Ag. Land	Ag. Land	Range	Range	Avg.
	as	as	as	as	Accuracy
	Ag. Land	Range	Range	Ag. Land	$\frac{A/A + R/R}{2}$
24 May MSS 5+7	71	29	93	7	82
12 June MSS 5	78	22	92	8	85
27 July MSS 5+7	83	7	91	19	87
Aug. MSS 5+7	62	38	93	7	78
Sept. MSS 5+7	55	45	94	6	75
Oct. MSS 5+7	46	54	95	5	70
Nov. MSS 5+7	59	41	92	8	75

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training fields are always selected from an area where ground truth is available using the spectral information on raw gray tone maps. Training fields are selected for all land cover categories within the study area. Using ground truth ensures that each category is represented. The training fields are analyzed by a clustering algorithm, however the training sample is limited to 10,000 pixels. Therefore, the analyst must be sure that each category is represented in the training sample.

Butte County and the surrounding area are somewhat unique. Within this relatively small area there is forest, rangeland, large area dryland farming, and irrigated farming. The basic crop in the dryland farming area is wheat. The basic crops in the irrigated area are corn and alfalfa. The irrigated fields are quite small in comparison to those found in other areas of intensive cropping in South Dakota.

This conglomeration of varying land use presents an interpretation problem by itself. But the major obstacle to accurate identification of land use in this area is the presence of clayey or dense clay soils, probably developed in shale. These soils (Figure 9) are very spectrally distinct from the loamy soils interspersed with them. The clay soils extend in a finger-like pattern from the northwest to the southeast corner of the county and adequate ground truth is limited in these areas. After selecting multiple training field samples and using many different clustering techniques, it was not possible to accurately identify land uses.

It appeared that most land uses outside the areas influenced by the clayey soils were identified accurately. Crop types that were randomly scattered in the soil problem areas were clearly a misclassification and generally a result of the high soil infrared reflectance. It was felt that lack of classification accuracy rendered the Butte County results unsatisfactory for SPB purposes.

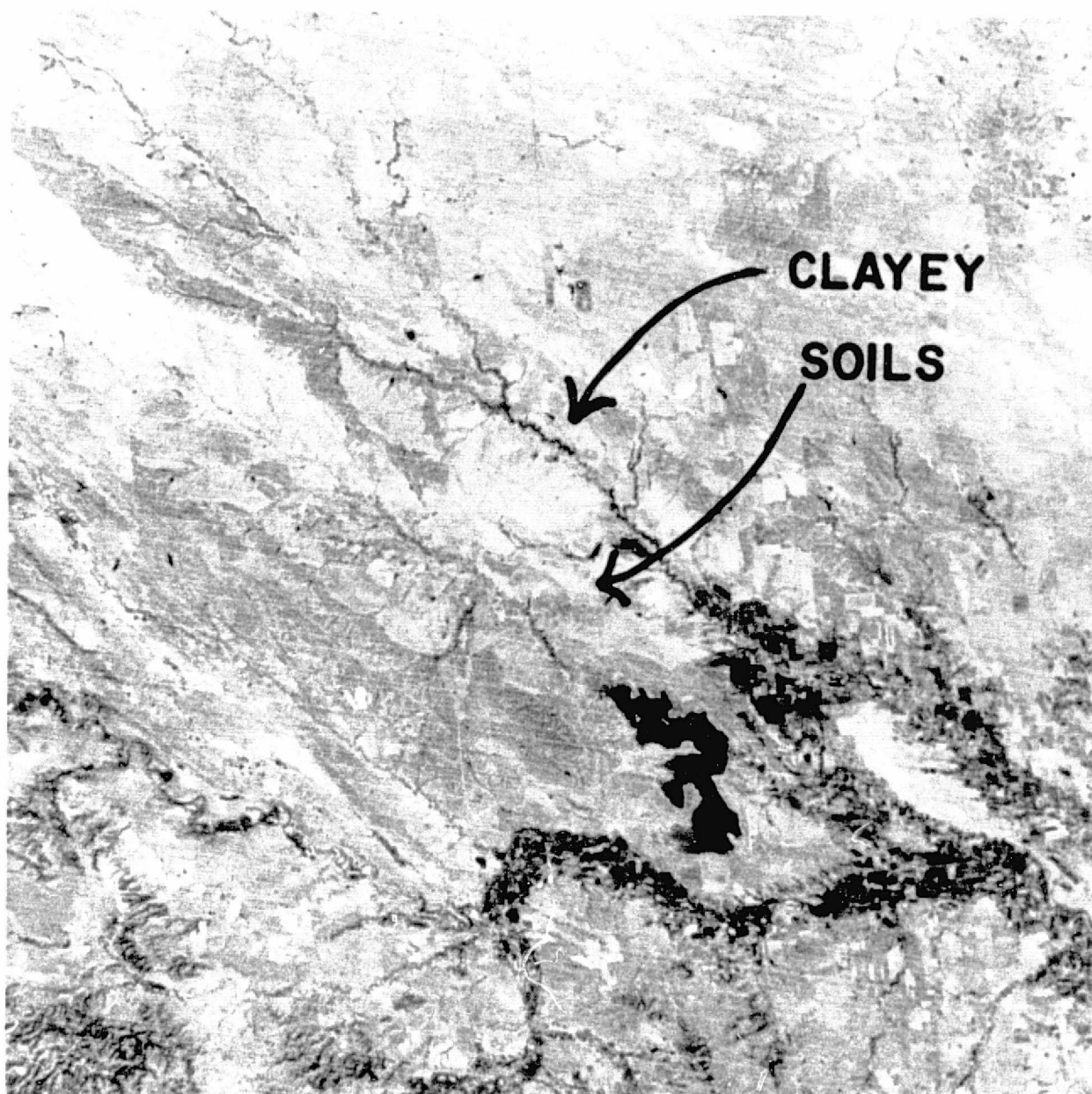


Figure 9. Portion of Butte County showing clayey soils as light-toned areas which inhibit digital analysis on 27 July 1975. Landsat MSS scene ID 2186-17004.

In order to improve the classification, it would be necessary to stratify the county. This would mean that the areas of loamy and clayey soils would be stratified and trained separately. Training fields in all categories in each area would have to be selected and analyzed separately, in effect developing a separate categorization for each. Once this was completed, the entire area could be categorized, with the proper statistics being used within each area. In this way, the background radiance discrepancy could be compensated for. This is a time-consuming operation not within the scope of this project. During FY 77, the multi-area classification technique will be implemented within LIMAP and, at that time, the county will be completed.

To assist in evaluation of comparable data and interpretive methods, a digital analysis of the ten-township area was conducted. Once again, problems with the analysis occurred. However, this time it wasn't due to the land use and soil types, but rather to the complexity of the data. The data analyzed was for July 27, 1975. An examination of the crop calendar of the basin, Figure 8, shows that at that time all small grains are in the process of being harvested. Also, corn is tasseling and alfalfa and hay are being harvested. The effect of all these phenomena is an "indecipherable hodgepodge" of spectral signatures and potentially twice as many spectral categories as there are thematic categories. The possibility of this kind of problem occurring was known before the analysis was begun. However, it was an objective of the project to make comparisons between analysis techniques. The cloud cover present in an earlier Landsat overpass rendered the July 27, 1975 data the best available. Unfortunately it was not very suitable for digital analysis. However, Level I was visually identified using the July 27, 1975 data with 88 percent of the accuracy of June RB-57 interpretations. An explanation of the difference in analysis methods may clarify the reasons why. Digital analysis methods usually concentrate on every

pixel (.45 hectare, 1.1 acre) whereas visual interpretations usually deal with a larger area. When doing visual analysis at Level I, the analyst looks for patterns such as field patterns. When performing digital analysis, the computer is the analyst. The algorithm can only evaluate reflectance values and fit these values into one of several categories. If digital analysis is to work properly, all categories must have spectral separability. However, when there are so many similarities between green, mature, and harvested crops and rangeland, it becomes very difficult to separate different land cover types. The visual analyst can use his knowledge of cropping patterns and vegetation growth stages to separate the land uses into Level I categories. The digital approach is limited in its use of such intelligence. Therefore, it is up to the analyst to ensure that the raw data provided to the algorithm is as free of confusion as possible. This means choosing the optimum dates of imagery. If an accurate digital classification is to be obtained, it is crucial to select imagery at a time in the growing season when crops and rangeland are as spectrally dissimilar as possible.

The "strip area" is located along Interstate 90 between Rapid City and Sturgis and is seen in Figure 10. The strip is in a valley between the foothills of the Black Hills and the geologic formation called the Dakota Hogback. Because of the adjacent Hills area and easy access to Rapid City, the state's second largest city, there has been a steady growth along the strip area and in the canyons and foothills. Some homes are being built on unstable land; sanitary sewage and water supply problems are compounded due to development location, and fire hazards are substantially increased as accessibility diminishes. A detailed Level II inventory is desired to assess the rate of development.

Landsat resolution is not adequate for a Level II inventory. Therefore, high and low altitude aerial photography was flown during June 1975 and was employed in the inventory. Interpretations were

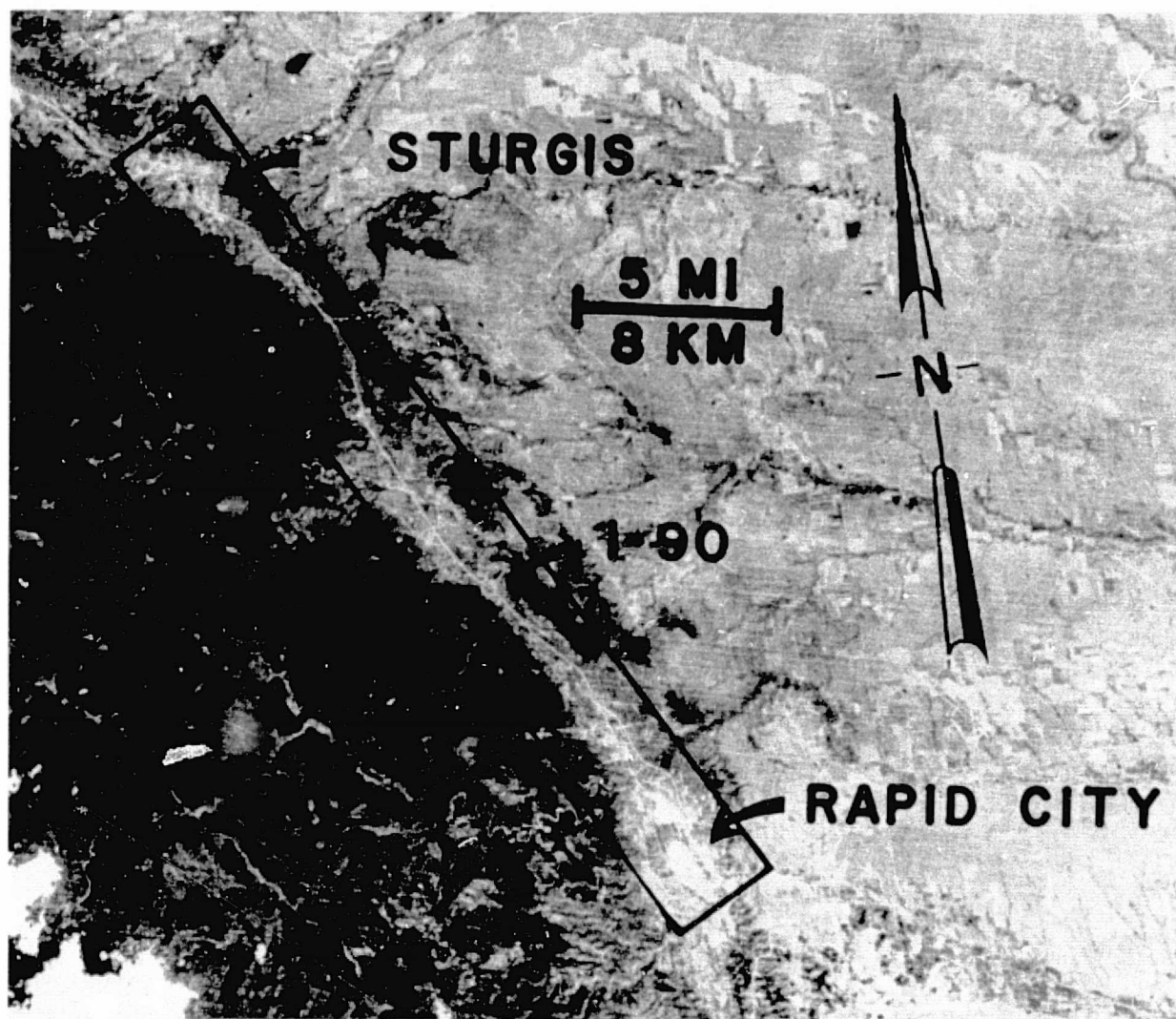


Figure 10. Strip study area as shown on Landsat MSS on 27 July 1975.

made at the scale of 1:24,000. High altitude data were enlarged, using the ZTS to match existing USGS Quadrangle maps of the area. The interpretation was coded onto mylar overlays. A narrow portion of the strip area was covered by low altitude photography. This imagery was viewed stereoscopically to verify questionable high altitude interpretations. High altitude photography did not offer adequate detail, within forested areas for the accurate interpretation of certain housing sites. More accurate interpretation of these canyon and forest homes was accomplished using stereo low-altitude photography.

A map of the Blackhawk Quadrangle is shown in Figure 11. The information was interpreted from 1975 high altitude imagery using low altitude data control. A similar interpretation for the area from 1974 high altitude imagery was available via the NASA Office of University Affairs, Grant No. NGL 42-003-007 (Figure 12). Note the extensive development in the southern portion of the 1975 map as compared to 1974.

As a result of these efforts, a map of the strip area has been developed. The map (Figure 13) is the result of the SPB interpretation of the June 1975 imagery. Such a base map, if periodically updated, could provide planning and zoning officials of both state and local governments a good development monitoring process.

A similar interpretation was conducted over an urban area within the Belle Fourche Basin. Using high altitude imagery as base data and stereo low altitude photography for classification verification, the city of Spearfish was mapped. The interpretation was conducted on a one acre cell basis and entered into a computerized data base. The cells were classified according to the dominant Level II category present. Color-coded results of the Spearfish interpretation are shown in Figure 14. Fourteen Level II land use categories have been identified and color-coded. Such a map is potentially available for every city in the state.

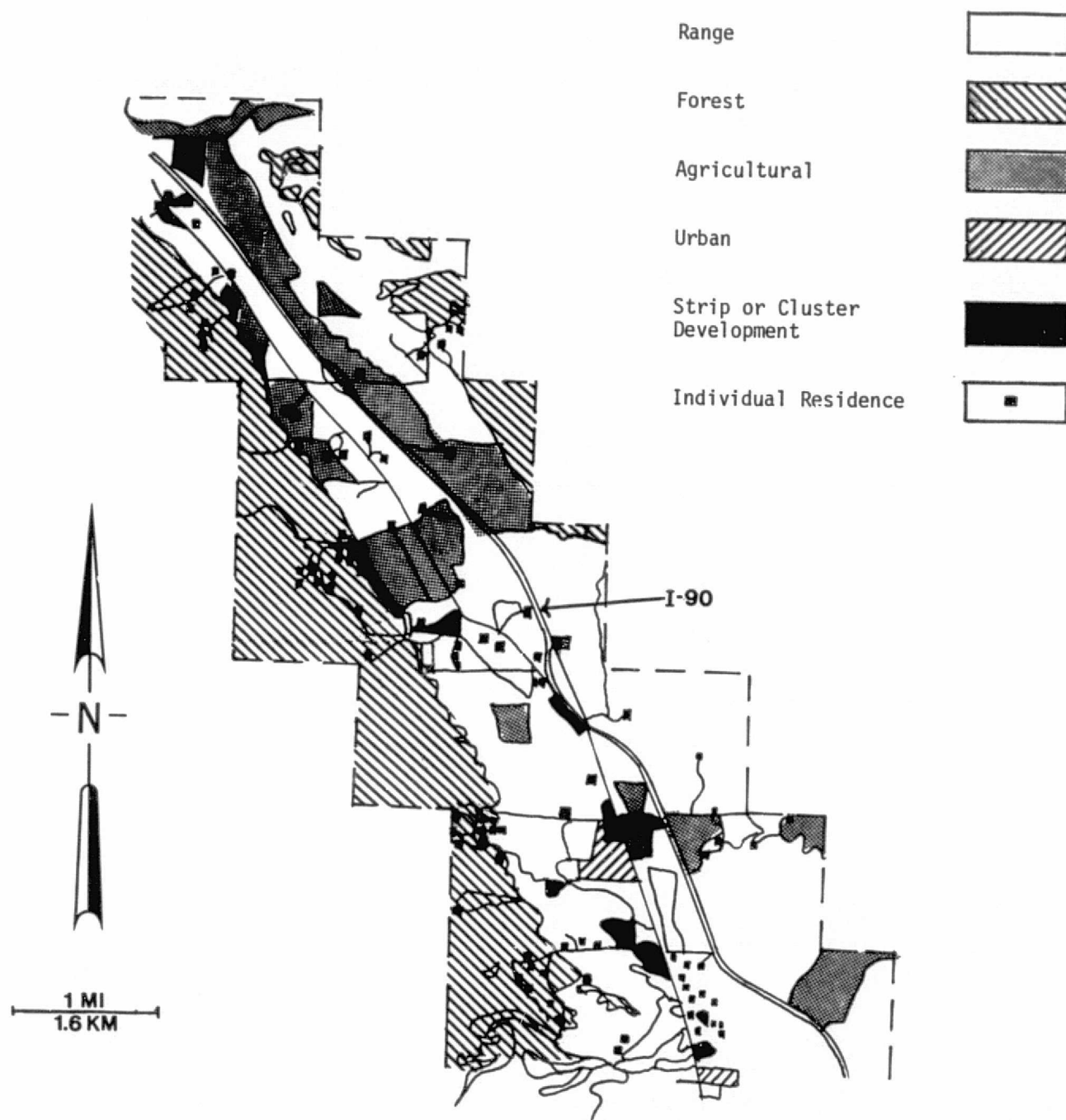


Figure 11. Land use along Sturgis-Rapid City Strip area as interpreted from 1975 aircraft data.

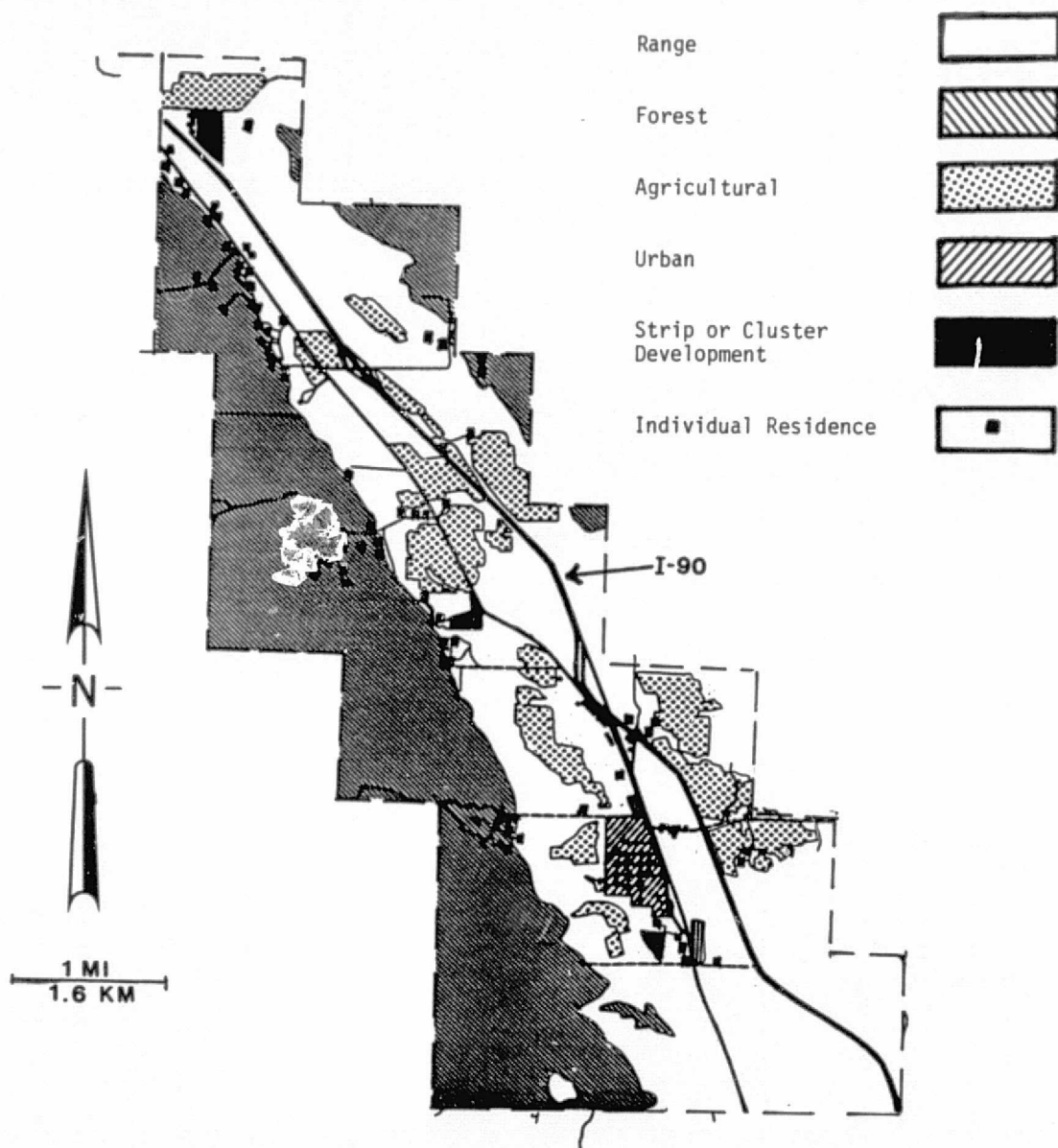


Figure 12. Land use along same area as Figure 11, interpreted from 1974 aircraft data.

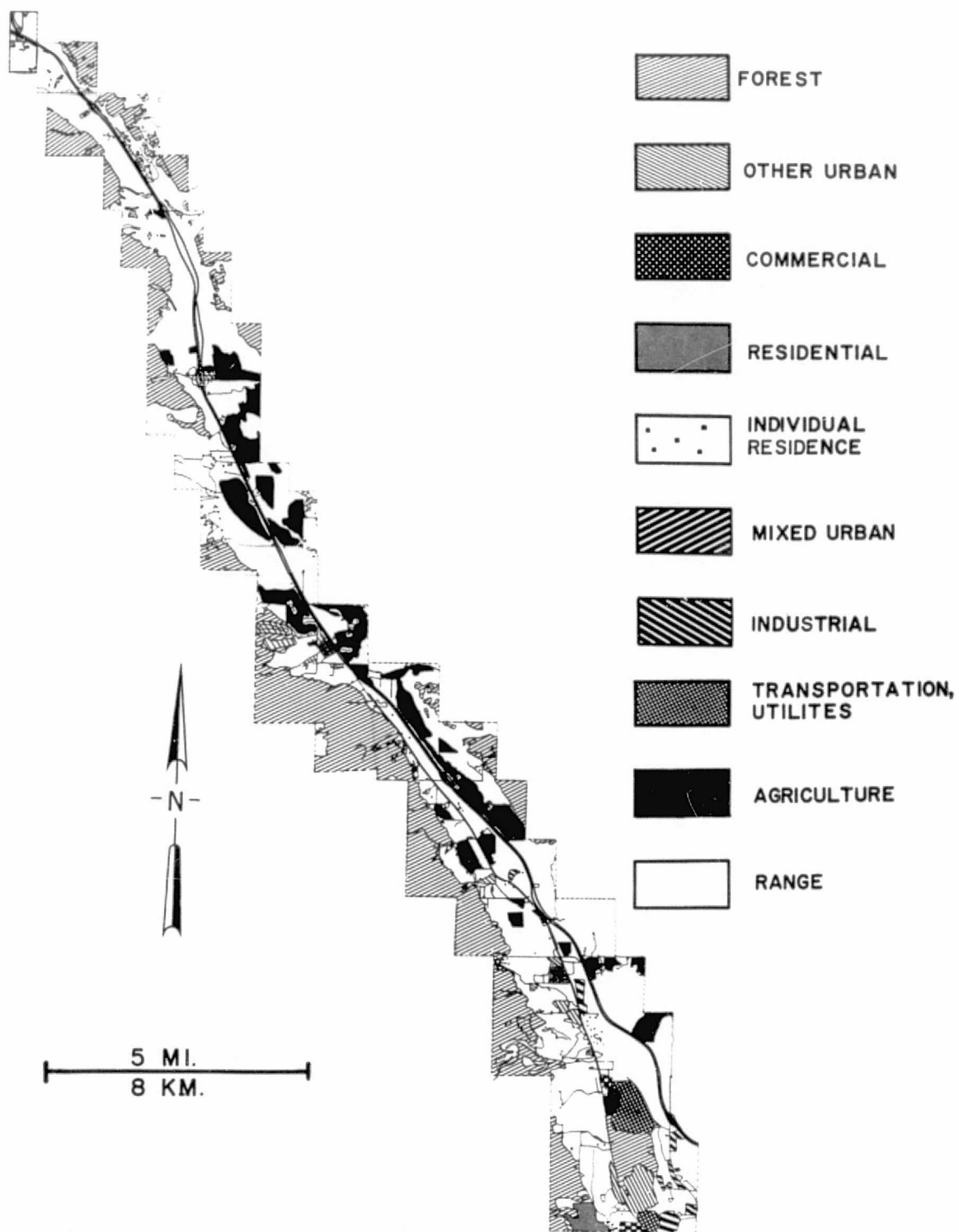


Figure 13. Land use of entire strip area as interpreted from 1975 high and low altitude aerial photography (reduced considerably for publication purposes).

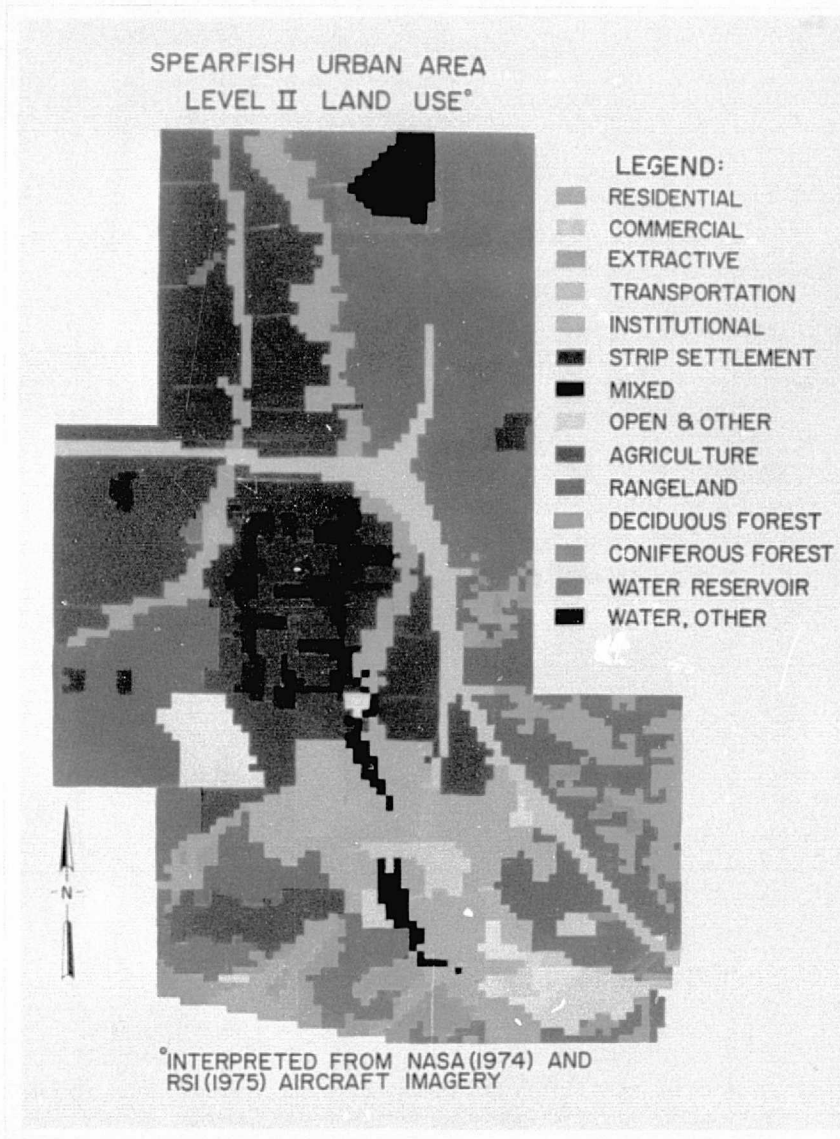


Figure 14. Level II land use of the Spearfish urban area as interpreted from 1974 high altitude and 1975 low altitude imagery. Data were coded into data base (see MAPCLASS section) and manually color-coded.

For Level I land use mapping procedures Landsat data are adequate for Western South Dakota. For visual interpretations of such imagery, it is desired to obtain color composite enlargements of approximately 1:125,000. Interpretation of such prints using mid June to late July Landsat imagery should allow mapping of agricultural land with accuracies in excess of 80 percent and rangeland in excess of 90 percent, based on field-for-field comparisons with high altitude aerial photography over the ten-township test area.

Digital analysis of Landsat CCT's requires more precise timing for the date of data collection with mid to late June being optimum for Western South Dakota. Varying soils and crop conditions also affect interpretation of CCT data. However when properly "trained", the computerized interpretation can produce greater than Level I land use maps.

Land use information systems requiring greater than Level II detail, are directed toward aerial photography. Both high and low altitude imagery is applicable with low altitude data being most desirable for very detailed or difficult interpretations.

Surface Water

The prairie areas included in the project have numerous small ponds built by area residents primarily for watering of livestock. These ponds vary in size from small dugouts of less than .2 hectare (1/2 acre) to over 4 hectares (10 acres). Wildlife indigenous to the area utilize these incidental to the primary purposes of livestock water. Therefore, the frequency and the distribution of these water bodies have a bearing on the wildlife potential of the region. Migratory waterfowl use these waters as resting and reproductive areas. The relative permanency, as well as the sizes, numbers, and distribution, have a bearing upon the well being of these migratory users. Past data on stock ponds were collected by means of on-site visual inspection, aerial photos, and pond-construction file data. Due to variable precipitation and runoff, the ponds may be full, dry, or even washed out. Tabulating pond data by traditional methods of

inventory is difficult. A better inventory can be obtained from a remotely-sensed approach and comparative data collected over shorter time spans would be more useful.

Analysis of data sources at different scales was initiated to provide a basis for evaluating Landsat as a surface water inventory tool. While surface water is a category in Level I land use, it is handled separately here. To be classified in a Level I land use classification, the surface area must equal or exceed 16.2 hectares (40 acres). In Western South Dakota there are numerous bodies of water which are considerably less than 16.2 hectares (40 acres). The number and distribution of these smaller bodies of water are important for evaluating the general water conditions throughout the basin. To inventory only 16.2 hectares (40 acres) and greater surface water bodies, as specified in Level I land use, would place serious restrictions on the reliability and usefulness of the surface water inventory. For these reasons, surface water is separated from the Level I classification and the surface water inventory capabilities of Landsat are separately investigated in detail.

Initial work centered on a physical accounting of the numbers of bodies of water. A basin-wide interpretation of surface water was conducted using 22.8 centimeter (9 inch) Landsat MSS 7 transparencies a 1:250,000 USGS Quadrangle map, and the ZTS. The ZTS field of view allowed up to nine townships to be viewed at one time. Once registered to the base map, drafting paper was placed over the map and the surface water was traced onto the paper using fine point drafting pens. Registration problems similar to those referred to in land use discussion were experienced in interpreting surface water. At a scale of 1:250,000 a difference of 0.25 centimeter (0.1 inch) was equal to 0.64 kilometer (0.4 mile). Such errors in locating points of water result in counting certain bodies more than once. So at this scale, both location and number are of questionable validity. Enlargement to 1:125,000 was attempted but registration to the base

map was difficult in areas where Landsat-visible features were not recognizable on the map.

Next, 1:250,000 scale MSS 7 prints of the Basin were interpreted for surface water (Figure 15). The total number of water bodies interpreted by different individuals is listed in Table 12. These were initial interpretations by participating agency personnel. A more detailed evaluation of surface water inventory capabilities was conducted within the outlined areas of Figure 15. The ten-township area is the same as that used for land use studies and is used here because of the available cloud-free imagery.

TABLE 12. 1:250,000 MSS 7 PRINT INTERPRETATION OF SURFACE WATER FOR BELLE FOURCHE RIVER BASIN.

Interpreter	Total No. Water Bodies
1	1721
2	2269
3	1421

The various interpretations for the ten-township area are listed in Table 13. Using the June color infrared high-altitude interpretation as a comparative base, the other interpretations are offered for review. Both the June and September high altitude color infrared film data sources were interpreted from the original film transparency on a light table. The interpretation of September high altitude imagery resulted in a comparative inventory value (percent of June aircraft inventory) less than the June aircraft data. This inventory reduction was attributed to discrepancies in surface water areas associated with late summer/early fall. Landsat interpretations were less than either the June or the September aircraft interpretations due to the resolution.

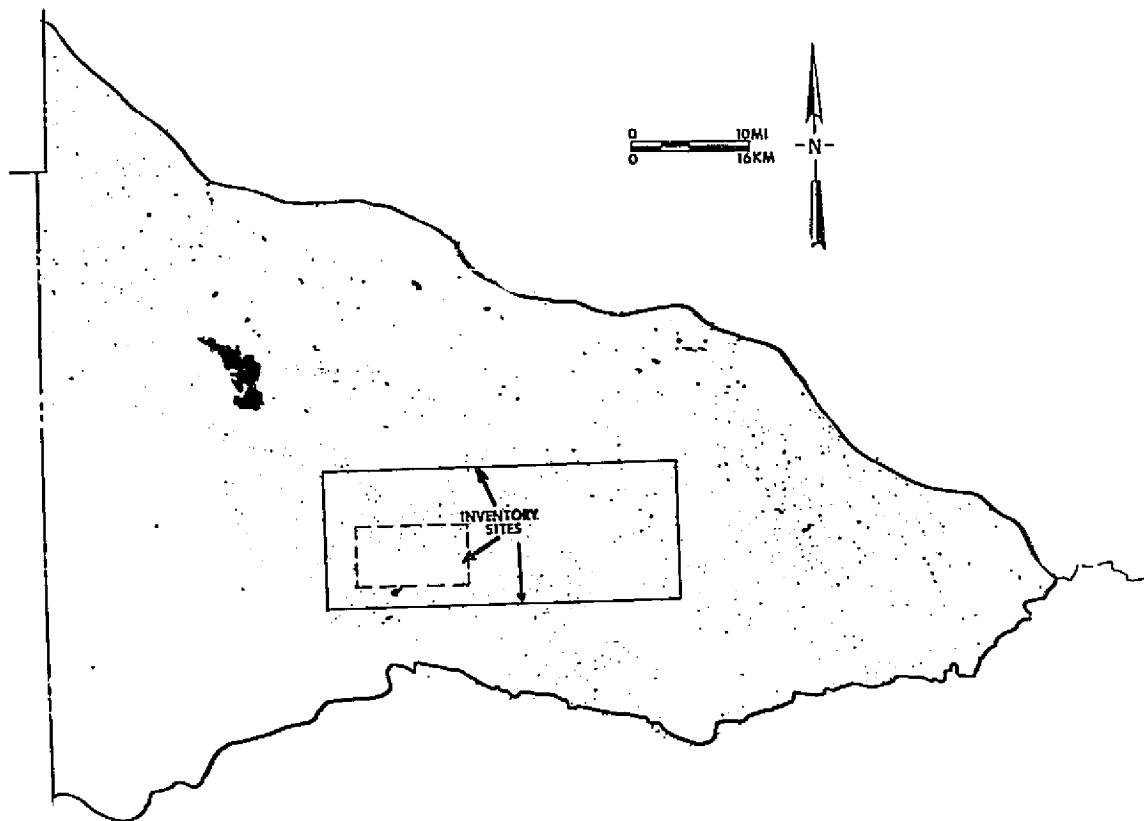


Figure 15. Surface water interpretation of the Belle Fourche River Basin as interpreted by DNRD personnel from spring 1975 Landsat MSS 7 imagery. Visual print interpretation was conducted at 1:250,000. The larger rectangular area is a ten-township site interpreted for water bodies from a variety of data sources. The smaller outlined area was interpreted with more detailed evaluation of Landsat inventory capabilities.

TABLE 13. SURFACE WATER INTERPRETATIONS FOR 10-TOWNSHIP TEST AREA (Townships 6 and 7 North)

Data Source	Data Date	Scale Interpreted	No. Water Bodies	Comparative Inventory Value
High Altitude Color IR Transp.	25 Jun 75	1:114,506	652	1.00
High Altitude Color IR Transp.	23 Sep 75	1:125,880	591	.91
LANDSAT MSS7; ZTS	12 Jun 75	1:250,000	488	.75
LANDSAT MSS7; Print	24 May 75	1:125,000	450*	.69*
LANDSAT MSS7; Print	12 Jun 75	1:250,000	294*	.45*
LANDSAT MSS7; Print	12 Jun 75	1:125,000	449*	.69*
LANDSAT MSS7; Print	27 Jul 75	1:125,000	222	.34
ASCS Mosaic; Print	Jun/Jul 68	1: 64,985	512	.79
High Altitude Color IR Transp.	25 Jun 75	1:114,506	274	1.00
LANDSAT MSS7; Print	27 Jul 75	1:125,000	102	.37
LANDSAT MSS7; CCT	27 Jul 75	N/A	105	.38

*Average of RSI, DNRD, and GF&P interpretations.

The average comparative value of the three 1:250,000 12 June print interpretations was 0.45. Enlargement of the 12 June data to 1:125,000 allowed for a substantial increase, .69, indicating advantage to using the enlarged print.

Interpretations of late July Landsat data indicated fewer water bodies were observable. This is, again, attributed to the intermittent nature of the smaller ponds in the area.

An ASCS photo interpretation was prepared by DNRD. This source was included because DNRD has interpreted surface water from such photographs for the entire state and is interested in comparing the results of their present procedures with what might be available using Landsat. The comparative inventory value of the ASCS interpretation (Table 13) was better than most Landsat interpretations.

A CCT of Landsat scene 2186-17004 (27 July, 1975) was rectified and level-sliced for surface water using SPB-developed software. Window selection allowed processing of only five townships in the ten-township study area. Color infrared and Landsat print interpretations were obtained for these five townships and are listed along with the digital data in Table 13. Results from the visual and digital procedures appear quite similar to each other in relation to the base high altitude data.

While general recommendations on scale and ideal dates for interpretation are inferred in this review, a more detailed analysis was required to give more specific information. This detailed analysis was conducted over the area outlined in Figure 15. Table 14 contains the results of this study. The comparative inventory values referred to above were measures of the ability of a variety of data sources to map all surface water (using June RB-57 color infrared imagery as comparative data base) irrespective of water body size. The basic pixel resolution cell for Landsat MSS is .45 hectare (1.1 acres) thus it was assumed that an interpretation categorizing surface water into those equal-to or less-than the basic cell area and those greater-

than the basic cell would be beneficial in analyzing the inventory capabilities of various Landsat interpretations. Base comparative data for this detailed surface water study were interpreted from black and white near infrared prints which were enlargements of high altitude 70 mm film. Ground surveys of selected sections within the study area convinced participating agency personnel that use of such imagery for base data is warranted. The interpretation resulted in the detection of 146 individual water bodies within this smaller test site. Of the 146 total water bodies on this more detailed base interpretation, over half were less-than or equal-to the basic Landsat pixel size. The total area of these smaller water bodies was 21 hectares (52 acres) whereas the area for the sixty-six larger classified water bodies was 73.7 hectares (182 acres). In other words, the larger (over .45 hectare [1.1 acre]) water bodies account for 45 percent of the total number, but 78 percent of the total surface area.

The apparent advantage of 1:125,000 Landsat interpretations over 1:250,000 Landsat is reinforced by the fact that for 12 June data, the average percent of base data (greater than .45 hectare [1.1 acre]) increased to .83 versus .75 for the smaller scale. However, at the larger scale (1:125,000) a larger percentage of mis-interpretations has occurred.

The registration difficulties previously referred to, regarding 1:250,000 interpretations from the ZTS, resulted in over estimating the number of water bodies by one third. Reasons for this have been reviewed previously.

The importance of time of the year of data collection is again revealed in that the May and June water bodies over .45 hectare (1.1 acre) composed 80 percent of base data. In late July, data allows inventory of 52 percent of the same base data. Climatological data for the weather station nearest the test area were obtained (11) and the reason July is appearing "drier" can be related to precipitation

patterns developed from the climatological data as graphed in Figure 16. From January to April 16 (the last day snow was on the ground) 11.2 cm (4.41 inches) of precipitation fell at the weather station. For twenty days prior to the July Landsat overpass, no precipitation was recorded. In a twenty day period prior to 12 June, a total of 5.8 cm (2.3 inches) fell, nearly 75% of which occurred in the five days prior to the 12 June Landsat overpass. In the twenty day period prior to 24 May, a total of 6.8 cm (2.7 inches) fell, 25% of which occurred in the five days prior to the 24 May Landsat overpass. It appears that the changing surface water patterns recorded by Landsat in the June-July period reflect changes induced by precipitation patterns. In summary, both year and time of year of data collection are important in the interpretation of base surface water inventories. Comparison of Landsat interpretations with water data on 1:24,000 Quadrangle maps reveals an important observation. In all but one Landsat interpretation (late July, for reasons discussed above) the larger water bodies were more accurately mapped using MSS 7 imagery. Figure 17 is a reproduction of the .45 hectare (1.1 acre) base high altitude data. Note the areas circled and labeled A through E. These five water bodies account for 10.9 hectares (27 acres) of surface water. Figure 18, the 24 May MSS 7 interpretation, indicates these five water bodies have been inventoried using Landsat visual interpretations. Later MSS 7 data (July 27), Figure 19, reveal the dynamic physical properties of certain water bodies. In general, the interpreted area appears drier at this time of year as compared to early in the summer, and note that water bodies C and D have disappeared. The USGS 1:24,000 Quadrangle map indicated surface water as shown in Figure 20. Note the absence of all five designated water bodies. Again the comparative accuracy of interpreting water bodies greater in size than .45 hectare (1.1 acres) from the 1953 1:24,000 USGS Quadrangle maps was equaled or exceeded in all but the late July Landsat interpretation. The importance of these statements can be reinforced when one realizes that 43 percent of the available 1:24,000 Quadrangle

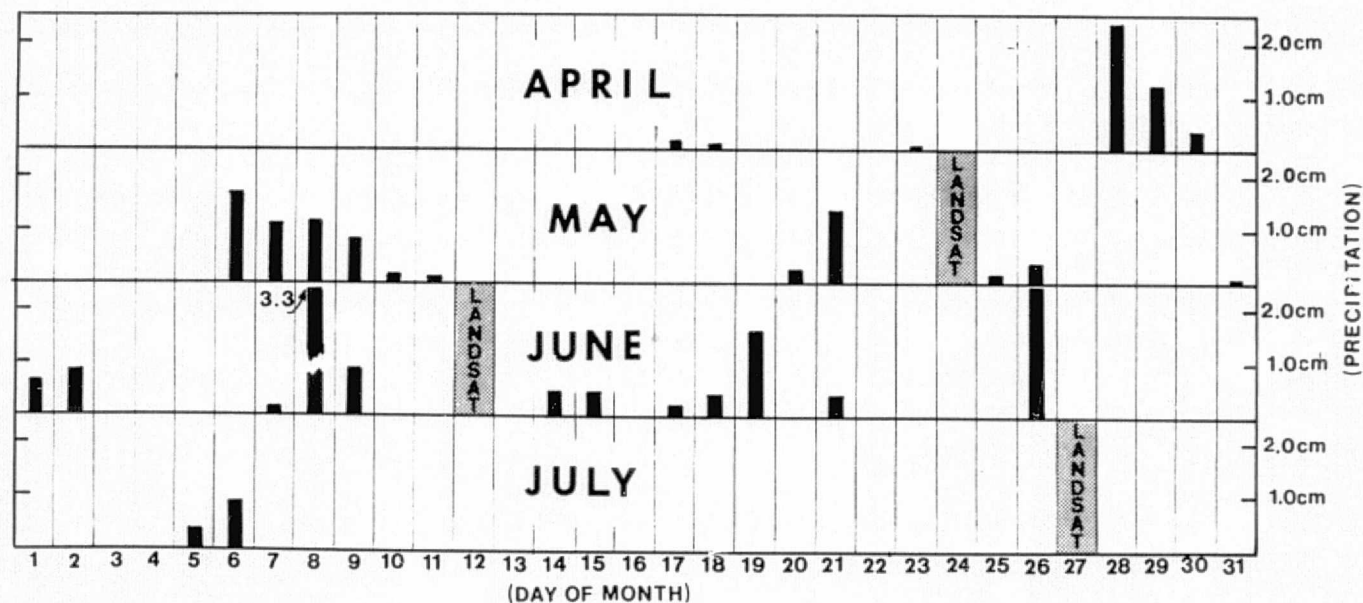


Figure 16. Precipitation data for April-July at Vale, South Dakota (within ten-township area). Shaded areas are indicative of a Landsat overpass. Precipitation patterns appear to be reflected in the variability of surface water on associated MSS 7 imagery.

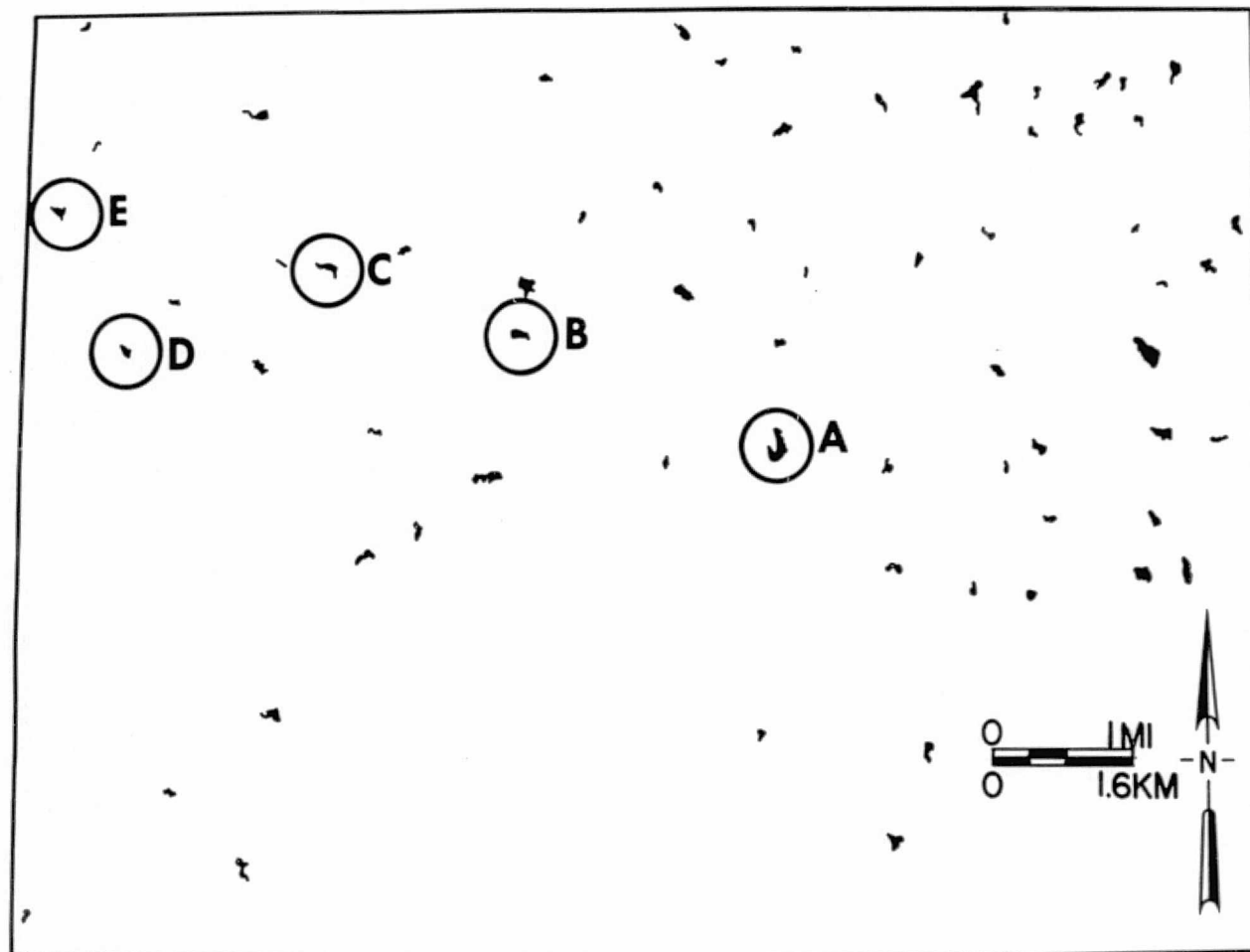


Figure 17. Reproduction of the $>.45$ hectare (>1.1 acre) high altitude base surface water data. Note the areas circled and labeled "A" through "E". Scale of interpretation: 1:24,000; date of data collection: 25 June 1975.

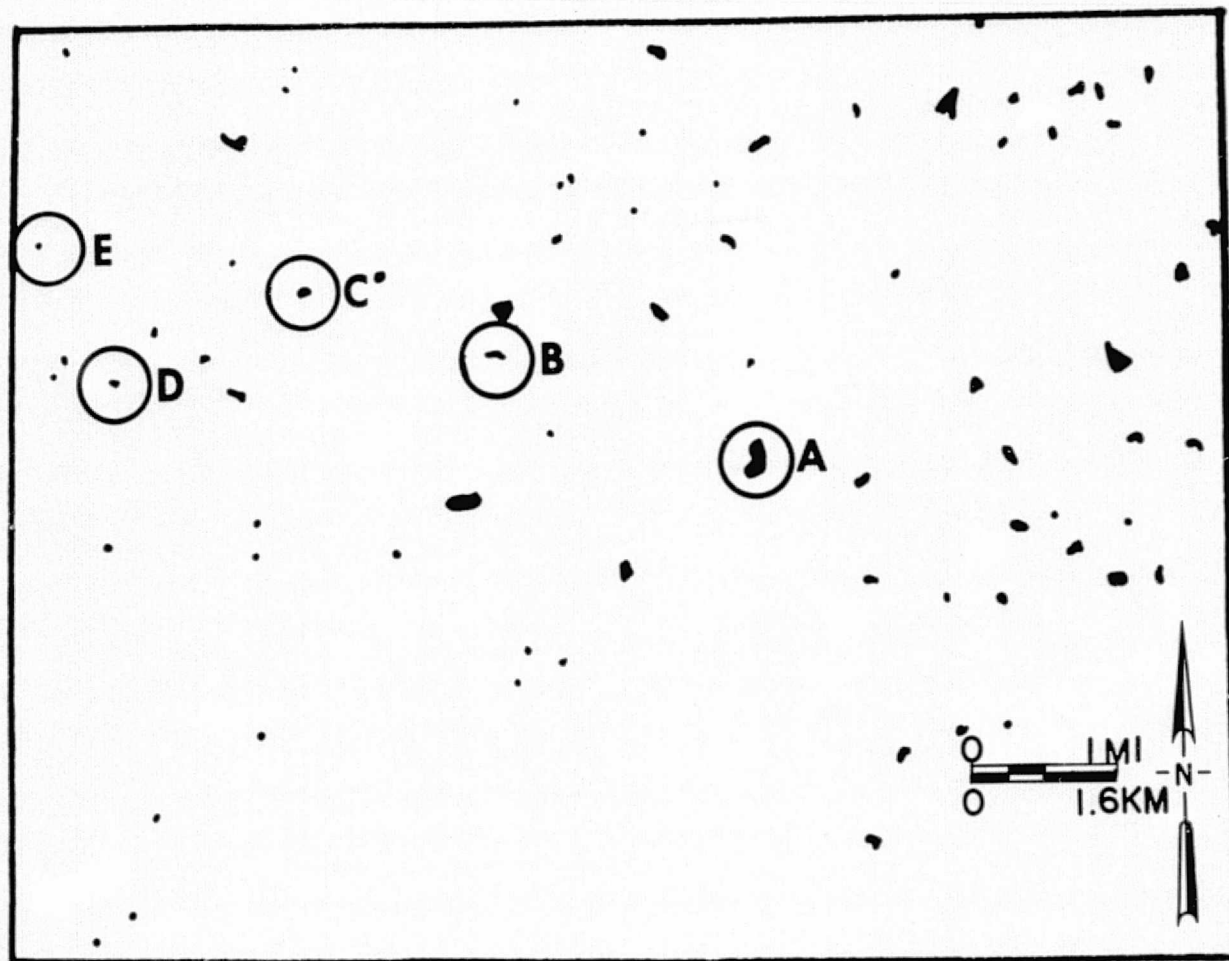


Figure 18. Reproduction of the 24 May 1975 MSS 7 surface water interpretation. Water bodies "A" through "E" have been inventoried on this 1:125,000 print interpretation.

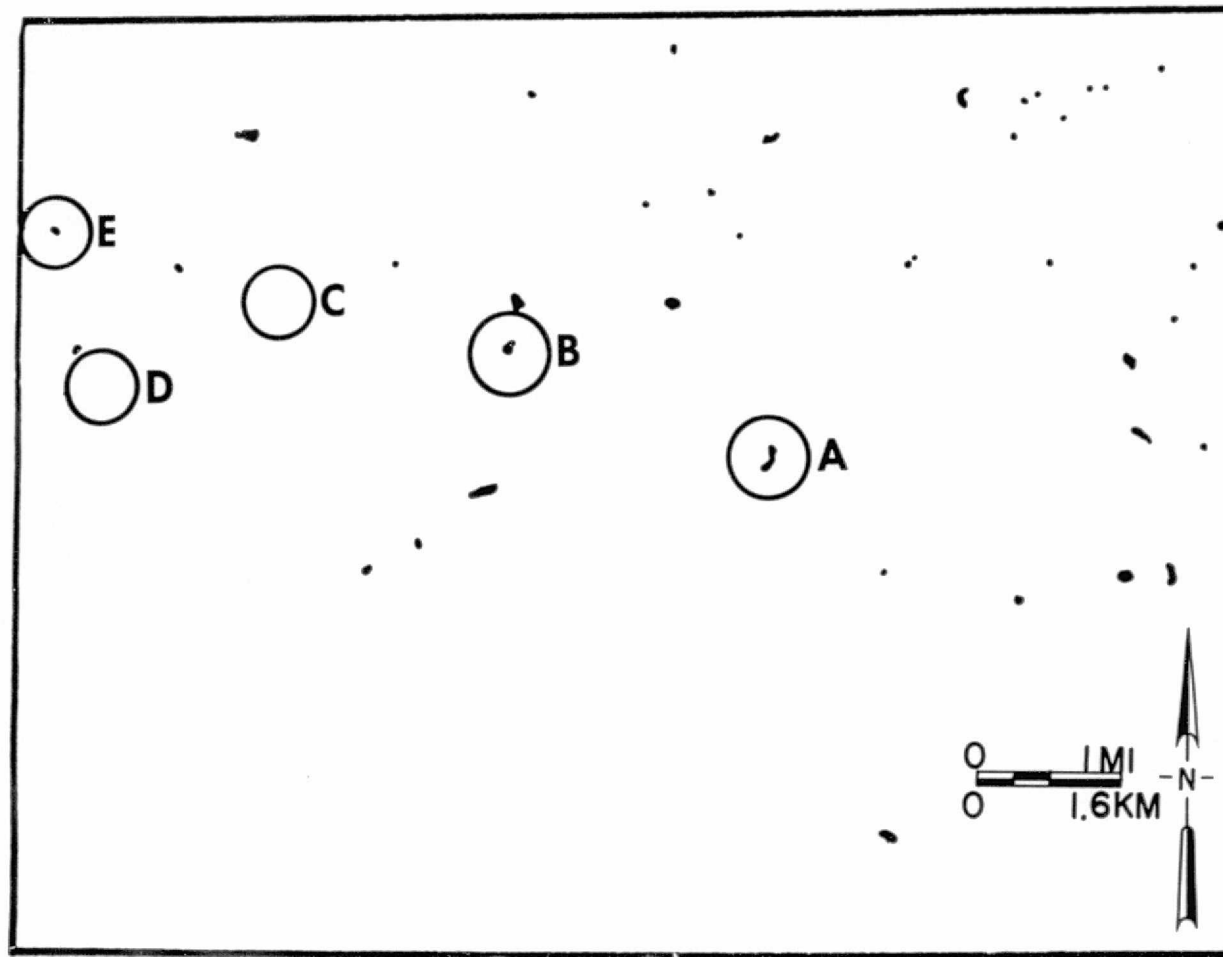


Figure 19. Reproduction of the 27 July 1975 MSS 7 surface water interpretation reveals the apparent dynamic physical properties of certain water bodies. In general, the interpreted area appears drier, as compared to the May interpretation of Figure 18. In particular, bodies "C" and "D" have apparently disappeared. Interpretation scale: 1:125,000.

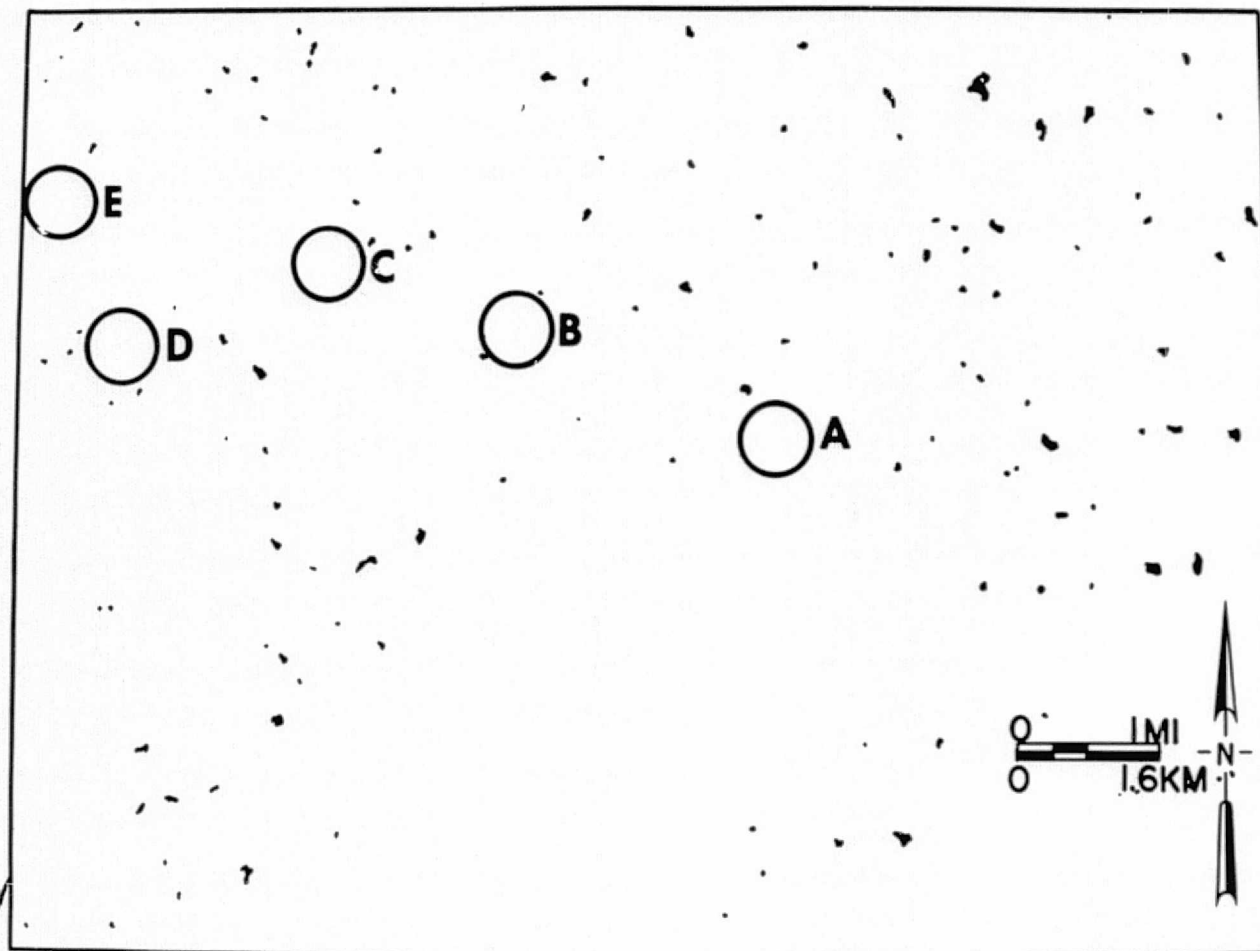


Figure 20. Reproduction of the 1953 1:24,000 USGS Quadrangle map as interpreted for surface water. Note the absence of all five designated water bodies.

maps for South Dakota are 20 years old or older, and that 42 percent of the state remains unmapped at that scale. Fully 73 percent of South Dakota is either unmapped at 1:24,000, or is mapped by 15-year old or older maps similar to those used in the above illustration (12). Even if the maps were available for the entire state, the cost of the approximately 250 1:24,000 maps required to map the area covered on a \$5 Landsat MSS 7 frame would be about \$200 (13). Even then, if the data used in map production were collected in late summer or during a dry year, the surface water data would probably not be as current as would be possible with more timely Landsat data.

Referring to Table 14, the ASCS interpretation resulted in 77 percent identification of water bodies over .45 hectare (1.1 acre). Interpretations of MSS 7 data produced "above 77 percent" figures in both the May and June 1:125,000 scale interpretations. The apparent resolution of the imagery is offered as explanation. The discrepancies between Landsat and ASCS interpretations of greater than .45 hectare (1.1 acre) water bodies are also attributed to the fact that the ASCS data were nearly ten years old. Also, part of the ASCS imagery was collected in July, a potentially dry period.

A Landsat CCT (ID #2186-17004, 27 July 75) for the same area was rectified and level-sliced for water using SPB-developed programming packages. The data in Table 14 indicate that threshold values were not low enough to allow detection of any of the less than .45 hectare (1.1 acre) water bodies. Program capabilities are being developed which would allow detection of some of these smaller bodies.

Table 15 provides low altitude aircraft data over a portion of area 6 which is also indicative of the seasonal variability of surface water referred to in earlier discussions. For the randomly selected sections, both the total number of water bodies as well as total surface area has decreased from June to September. Data were further refined by subdividing the surface area measurements into categories as listed in Table 16. For the sections under consideration, the largest number of water bodies are less than 0.2 hectares

TABLE 14. DETAILED SURFACE WATER ANALYSIS

Data Source	Data Date	Scale	Total No. Water Bodies	Percent of Total Which Is Not Water	Percent of Base Data Interpreted	
					<.45 ha (1.1 acre)	>.45 ha (1.1 acre)
					Base Data	
High Altitude Black and White Print	25 Jun 75	1: 24,000	146	0	100	100
High Altitude Color IR Transp.	25 Jun 75	1:114,506	113	8	49	98
Landsat MSS 7; ZTS	12 Jun 75	1:250,000	90	36	5	82
Landsat MSS 7; Print*	24 May 75	1:125,000	93	22	17	81
Landsat MSS 7; Print*	12 Jun 75	1:250,000	59	13	4	75
Landsat MSS 7; Print*	12 Jun 75	1:125,000	85	23	10	83
Landsat MSS 7; Print	27 Jul 75	1:125,000	38	8	1	52
Landsat MSS 7; CCT	27 Jul 75	N/A	35	23	0	42
USGS Quadrangle Map	1953	1: 24,000	119	24	55	70
ASCS Mosaic; Print	Jun/Jul 68	1: 65,985	100	23	31	77

*Average of three interpretations.

(0.5 acre) with a majority being less than 0.4 hectares (1 acre).

TABLE 15. SURFACE WATER DATA FROM LOW ALTITUDE AIRCRAFT IMAGERY.

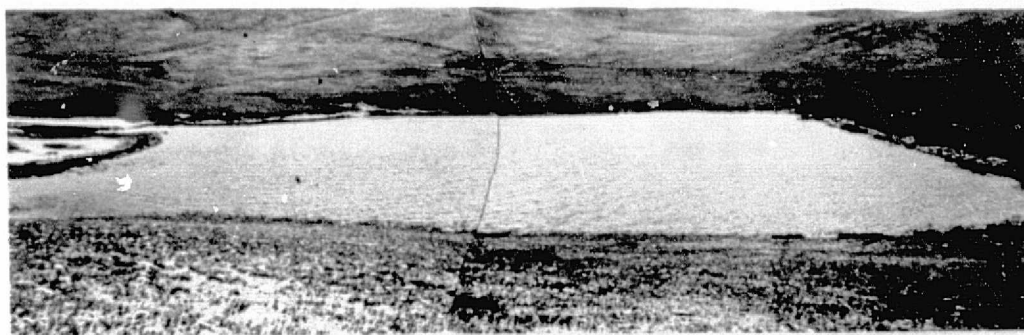
Sec. No.	June			Sep		
	No.	Hectares (acres)		No.	Hectares (acres)	
21	7	1.6	(4.0)	7	1.1	(2.7)
28	11	.5	(1.2)	7	.6	(1.5)
20	15	4.6	(11.4)	13	2.8	(6.9)
27	6	12.8	(31.6)	5	12.5	(30.9)
TOTALS	39	19.5	(48.2)	32	17.0	(42.0)

Figure 21 shows a water body in Section 11, T6NR6E from the ground, as it appears in high altitude black and white infrared and in Landsat MSS 7 imagery. The stockdam is 1.1 hectares (2.7 acres) and is readily interpreted on Landsat imagery. However, as discussed above, those less-than 0.48 hectares (1.2 acres) were difficult to see. These small water bodies comprise approximately half the stockdams in the Belle Fourche River Basin and are important as a source of water for livestock and wildlife in the rangeland and crop areas. It is estimated that, although high in number, these smaller reservoirs comprise 15 percent of the total surface water area in the basin. If this were true for all state basins, Landsat data would be acceptable for general inventory purposes. However, each basin has different characteristics and each basin would require adjustments with respect to its own features.

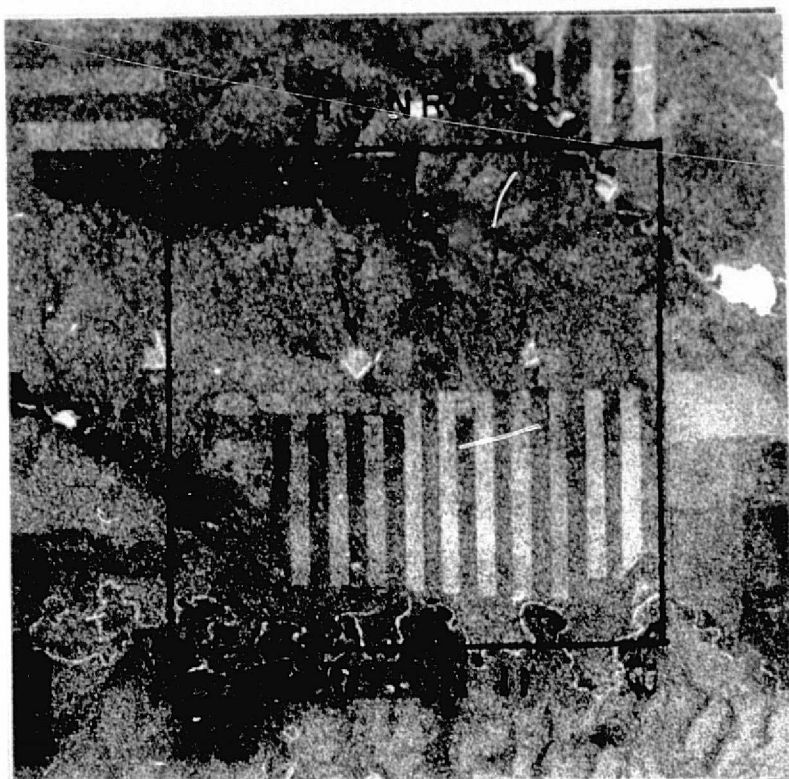
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TABLE 16. SIZE DATA ON SURFACE WATER FROM LOW ALTITUDE AIRCRAFT IMAGERY.

Size Class, hectares (acres)	June			September		
	No.	Total hectares (acres)		No.	Total hectares (acres)	
<.04 (<.1)	11	.2	(.5)	10	.3	(.7)
.04-.2 (.1-.5)	22	1.8	(4.5)	17	1.7	(4.3)
.2-.4 (.5-1.0)	2	.6	(1.5)	2	.6	(1.5)
.4-.8 (1.0-2)	1	.7	(1.8)	1	.5	(1.3)
.8-2.10 (2-5)	2	3.8	(9.5)	1	2.0	(5)
>2.0 (>5)	1	12.1	(30.0)	1	11.8	(29.5)
TOTALS	39	19.4	(47.7)	32	16.9	(42.3)



a



b



c

Figure 21. Views of surface water as it appears a) on the ground, b) on high altitude black and white 80 mm Hasselblad (89B filter), and c) on 12 June 75 Landsat MSS 7 imagery, (scene ID 5054-16504).

Drainage Systems

Drainage network analysis information is extremely important for a complete hydrological inventory of any region. The network is essentially the pattern or arrangement of the natural and man-made stream channels which have developed within an area. If a basin is well drained, surface runoff concentrates quickly. Such a basin characteristically has high peak floods and low minimum flows, i.e. drainage is flashy. Poorly drained areas are correspondingly less flashy. Where properly analyzed, a drainage network can provide a hydrologist with an index of basin permeability and an indication of yield. This is possible because the character of the natural erosion of stream channels is related to and restricted by the type of materials from which the channels are carved (14).

An accurate drainage map of the Basin does not exist, so an effort was put forth to develop and demonstrate a procedure to produce such a map. The basic premise was to work from available 1:24,000 Quadrangle maps. The drainage information on these maps was considered as the best available data. Where maps were not available, high altitude aerial photography was used as the prime data source. Where neither map nor aerial photography was available, Landsat imagery was the prime data source.

The procedure developed is as follows: Transfer drainage information from 1:24,000 Quadrangle maps to velum and update information by temporal Landsat and high altitude interpretation. Where maps are unavailable, a ZTS and high altitude transparency and temporal Landsat were used to develop requisite drainage data using 1:125,000 county highway maps for registration purposes.

For areas where no aerial photography or maps are available, drainage information is obtained from a combination interpretation of winter black and white and summer color composite Landsat prints. The winter scene accentuates certain drainage features via the combined effects of snow-cover and sun angle. In very flat areas, the winter data are difficult

to interpret. For these areas, the color composite provides drainage indicators such as vegetation along streams and soil erosion signatures. A combination of the two seasons allows for the generation of a Landsat-based drainage map in areas devoid of other data.

County highway maps exist for every South Dakota county. These maps contain drainage information in addition to the expected highway information. For those areas unmapped at 1:24,000 by the U.S. Geological Survey (42 percent of the state), the highway maps are the only existing source of drainage data. Ground verification of approximately 40 locations allowed for direct comparison between the Landsat-based drainage network and that associated with county highway maps. Areas checked were those where the two maps were in disagreement as to drainage location and/or direction. An example of such an area can be seen in Figure 22. Figure 22(a) is a reproduction of the highway map drainage and Figure 22(b) is the same area as interpreted using temporal Landsat imagery. The circled area is that visited on the ground. The ground truth photograph, Figure 22(c), reflects the obvious presence of a drainage system as interpreted from Landsat imagery. For the 40 sites, the Landsat interpretation was deemed most correct in all but five cases.

When drainage networks had been interpreted from the various sources, they were photographed and printed to the same scale for preparation of a controlled network mosaic. The mosaic was then re-drafted as the final drainage map. The drainage network and sub-basins are seen in Figure 23.

Rangeland Use

Hundreds of thousands of acres of Missouri River bottomlands were inundated due to the construction of Oahe and Big Bend Dams in South Dakota. The U.S. Army Corps of Engineers was to identify the best plan to mitigate wildlife habitat losses incurred through the submergence of these bottomlands (15). The South Dakota Department of Game, Fish and Parks was designated to provide wildlife management plans to the Corps

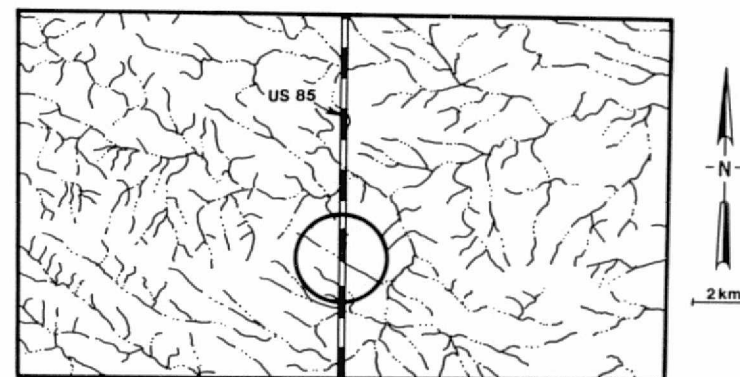
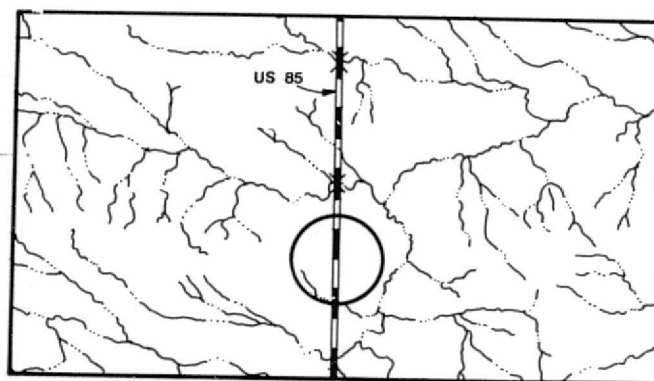


Figure 22. Drainage information contained on a portion of the Butte County Highway map is seen in (a). A Landsat-based drainage network for the same area is depicted in (b). The circled area shows the interpreted presence of a drainage pattern using Landsat but no such data exists on the highway map. This is one of the 40 conflicting points checked on the ground. The actual condition is seen in Figure (c). As in 35 of the 40 visited points similar to this, the Landsat interpretation appears more indicative of actual conditions.

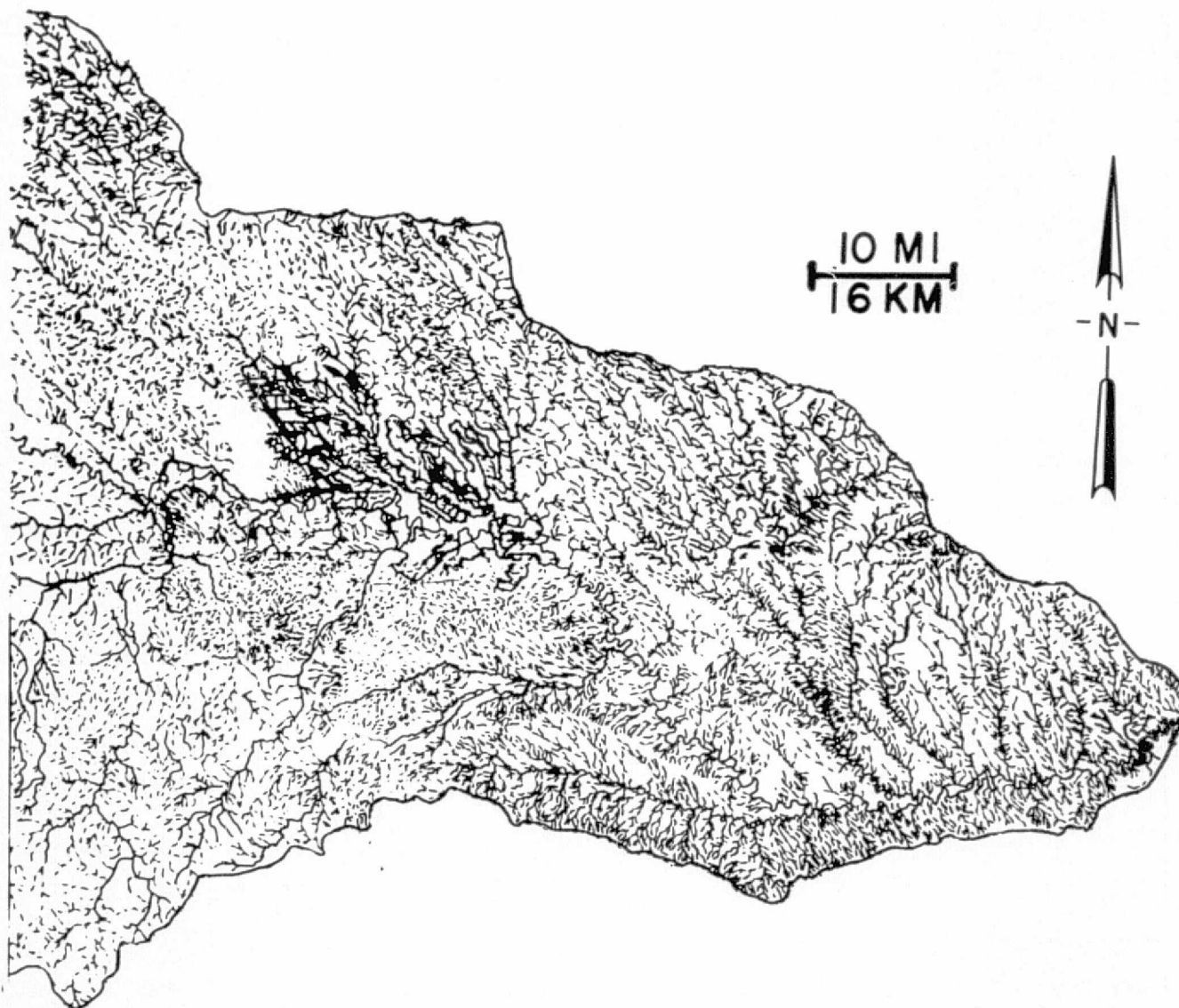


Figure 23. The drainage network of the Belle Fourche River Basin as interpreted using Landsat based procedures.

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of Engineers for the potential mitigation lands. Landsat satellite imagery and aircraft imagery were used in the preliminary evaluation of one of these mitigation areas.

Five areas were initially under consideration by the Corps of Engineers. Of the five, one site was located within the study area of this project at the confluence of the Belle Fourche and Cheyenne Rivers, Figure 1.

GF&P personnel were to prepare management plans for each of the five considered mitigation areas. On Thursday, November 13, 1975, GF&P personnel relayed the information to RSI that the deadline for plan submission had been substantially advanced. Management plans were to be formulated by Wednesday, November 19. An RSI representative met with the GF&P range specialist designated to prepare the Two-Rivers plan on Monday, November 17. Color and color infrared high altitude prints and Landsat MSS 5 and 7 enlargements were prepared and taken to the working meeting. Also prepared was a black and white (red filter) mosaic of low altitude data over portions of the ranch area. Soils information as interpreted from Landsat and aerial photography (previously done through RSI, NASA Grant NGL-003-007) was also included in the supplied data. Preliminary discussions resulted in the definition of specific information required by GF&P for input into the development of the Two-Rivers wildlife management plan. Timely information on surface water, land use, timbered areas, and soils would substantially enhance the "reliability" of the resultant plan.

The proposed mitigation land boundary was transferred to Landsat MSS 7 imagery, Figure 24. Surface water interpretations were conducted from early spring (wet) and mid-summer (dry) Landsat data printed as a negative image. In such an image, areas of low infrared reflectance (e.g. surface water) will show up as white. Interpretation of such data allowed development of basic conclusions regarding the approximate acreage of and the relative permanence of Two-Rivers area surface water. This was used in the evaluation of the site for wildlife habitat, and in the determination of potential fish stocking areas.

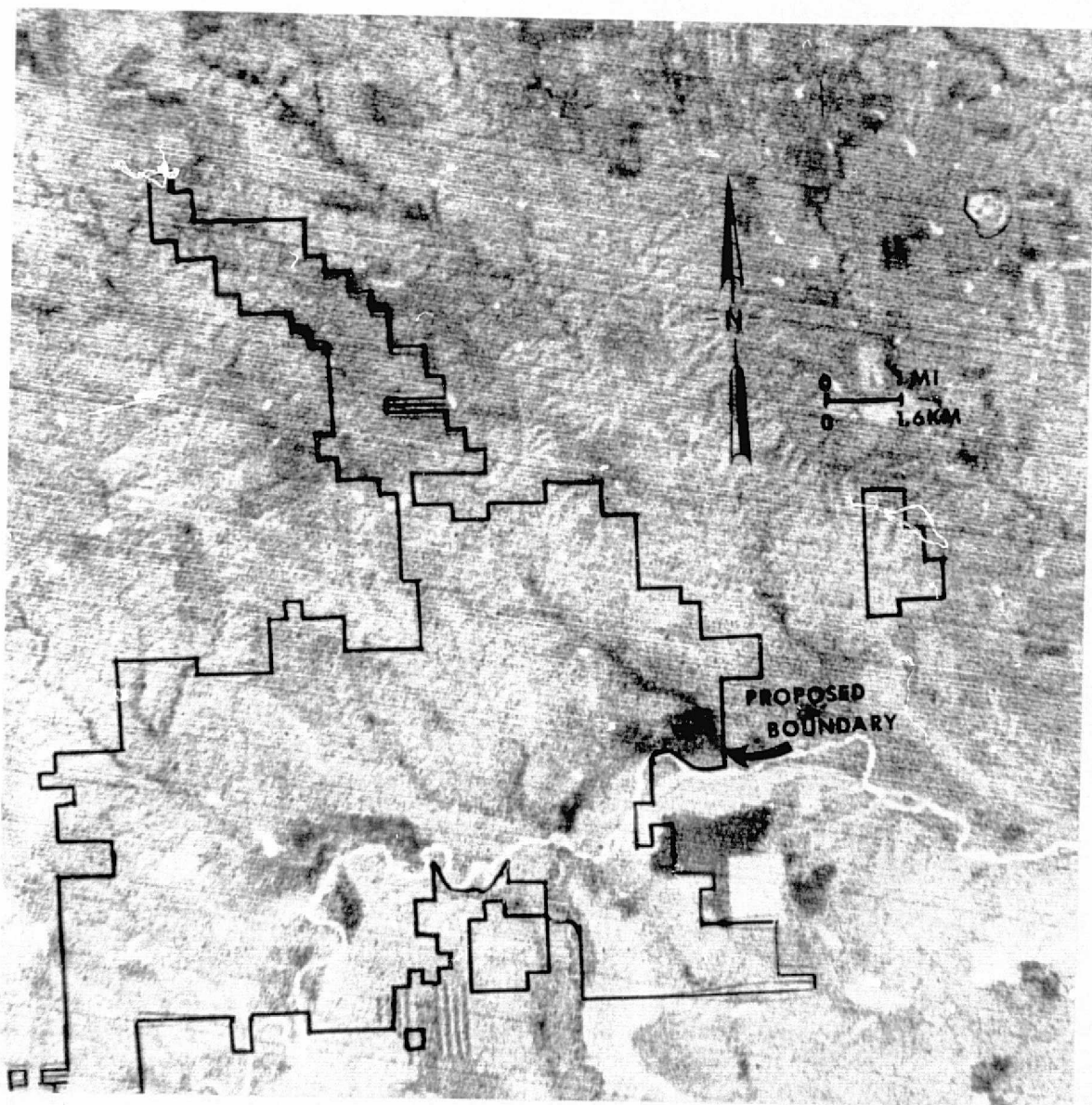


Figure 24. Proposed boundary of mitigation land as transferred to Landsat MSS 7 of 26 July 75.

The interpretation procedure was simple. Plastic overlay material was placed on the early spring, black and white Landsat print. A waterproof marking pen was used to interpret surface water from the print. Using available maps, the photo scale was determined. To estimate the surface area of water, a graph paper grid was placed under the interpretation. The photo scale was used to calculate the area of a grid cell. Both the number and approximate size of interpreted water were recorded.

In terms of water supply and resultant game distribution/production, it was determined that information on the lands adjacent to the proposed mitigation land would be of value. Such data would allow basic recommendations to be formulated pertaining to the availability and distribution of water within the ranch area as compared to the land surrounding the site. Interpretations similar to those conducted for the ranch area were conducted on a 19x23 km (12x14 mi) area surrounding but excluding the proposed mitigation area. The results are in Table 17.

Table 17 shows that the density of surface water in terms of hectares of water per square kilometer of land is less on the proposed mitigation ranchland than on the surrounding ranchland. The numerous Western South Dakota stockdams provide resting areas for waterfowl during migrations and often provide waterfowl nesting and rearing areas during breeding season. The impounded water also serves to support a variety of other wildlife species from small to large game. If the proposed mitigation land was to be developed as a wildlife habitat, it would be desirable that surface water available on the habitat be comparable in area and distribution to that on the surrounding lands. In order to bring the mitigation lands up to the surface water density of surrounding lands, eight additional 2.5 hectares (6.25 acres) impoundments would be required.

Comparison of interpretations for wet and dry seasons resulted in the conclusion that all 14 bodies of water within the ranch boundaries were relatively permanent and could be considered for fish stocking. By contrast, a number of the surrounding 45 water bodies were considered

TABLE 17. SURFACE WATER DATA FROM EARLY SPRING LANDSAT IMAGERY.

	Two-Rivers Ranch	19x23 km area (excluding ranch) (12x14 mi)
Total surveyed area, hectares (acres)	14,459 (36,148)	29,087 (72,717)
Number of water bodies	14	45
Surface water area, hectares (acres)	35 (87)	114 (285)
Average water body size, hectares (acres)	2.5 (6.2)	2.5 (6.2)
Density:		
$\frac{\text{hectares water}}{\text{km}^2}$ $\left[\frac{\text{acres water}}{\text{mi}^2} \right]$	.24 (1.54)	.39 (2.50)
$\frac{\text{number of water bodies}}{\text{km}^2 \quad (\text{mi}^2)}$	.1 (.18)	.15 (.27)

intermittent and not suitable for stocking considerations.

The two major land use categories for the considered area are rangeland and agricultural land. Available Corps of Engineer land use data recorded 1,200 hectares (3,000 acres) were under cultivation on the Two-Rivers Ranch. Interpretation of Landsat MSS 5 imagery for surface water resulted in the data contained in Table 18.

TABLE 18. AGRICULTURAL LAND USE FROM LANDSAT DATA

	Two-Rivers Ranch	19x23 km surrounding area (excluding ranch) (12x14 mi)
Total area, hectares (acres)	14,459 (36,148)	29,087 (72,717)
Agricultural land area, hectares (acres)	1,200 (3,000)	7,800 (19,500)
Percent agricultural land	8.3	26.8

The differences between Corps of Engineer data and the Landsat data were not disputed by Corps officials. The croplands on the proposed mitigation area are potential sources for wildlife food crops and might serve as "buffers" to adjacent landowners. Surveys of land use patterns in a large diameter "zone of influence" could provide pertinent data for evaluating the impact of the introduction of a wildlife production area and the potential effects induced by such a land use conversion.

Low altitude aircraft imagery was available for about 60 percent of the area. A mosaic of black and white (red filter) prints was prepared and taken to the working meeting. The red filter imagery provided easy interpretation of a healthy green vegetation since it shows up as very dark. A plastic overlay was placed on the mosaic and timbered areas

were visually interpreted. Acreages of timberland were estimated using the same grid method described earlier. The area covered by the mosaic was accepted as a representative sample of the ranch and overall timber areas were estimated. The GF&P representative had previously visited the area and was familiar with the timber types within the draws and bottomlands. With this knowledge, a summary was developed of the types of wildlife which might be supported in the area.

A soil association map of Meade County was produced using Landsat and aircraft imagery in conjunction with existing soils information. This soil association work was implemented by RSI on NASA Grant NGL-003-007. During the November working meeting, the various soil associations within the area were cross-referenced to an interpretive guide. The guide assisted the GF&P representative in evaluating the vegetation support capabilities of area soils and, subsequently, the ability of the area to support wildlife.

Data visually interpreted during the five-hour working session between RSI and GF&P personnel were used as direct input to the management plan. It is questionable whether or not any other source of data could have provided the extent of data interpreted from Landsat and aircraft imagery in the existing time constraints.

Floodplain Delineation

Floodplain analysis is of interest to the State Planning Bureau and through the aid of data collected during this project, the SPB was able to evaluate the usefulness of aerial photography in delineation of floodplains. The Belle Fourche River and Redwater Creek confluence near Belle Fourche, South Dakota, forms the primary study site. The site was selected because it is the location of a city within the flood areas of these two river systems and because of the available USGS maps for the area.

Visual interpretation of a high altitude 22.8 centimeter (9 inch) imagery transparency was conducted using a ZTS in conjunction with a 1:24,000 USGS Quadrangle map. One interpreter mapped the floodplain from

the aerial photograph registered to the map and a second person interpreted floodplain boundaries from the contour map of the area.

The results of the two interpretations are shown in Figure 25. A difference of 585 hectares (1146 acres) resulted. In areas of steep slope, such as area "A", both interpretations were in agreement in the location of floodplain edge. In areas of gentle slope there were considerable differences in location of floodplain edges. It was found that an interpretation of only contour lines resulted in difficulty when the contour interval is 3.05 m (10') or less and the distance between contour lines approaches 402.3 m (1320'). In such areas, high altitude imagery proved most useful. The interpreter is able to use various surface-related signatures such as soil types vegetation differences, and the effects of previous floods. It is felt that optimum floodplain mapping can be obtained by using both data sources complementary.

Water Quality

Considerable effort was expended in ground truth data collection for water quality studies. Areas 1, 3, 4 and 5, Figure 1, were the selected locations of flow and quality sampling stations. Area 1 included one sampling point above Spearfish, one midway between Spearfish and the mouth of Spearfish Creek, one on the Redwater River above the mouth of Spearfish Creek, and one on the Redwater below Spearfish Creek. Sampling at area 4 included a point above Lead and two below Deadwood. These measurements were taken in cooperation with the South Dakota Department of Environmental Protection and the U.S. Geological Survey. GF&P personnel coordinated ground truth data collection on June 25-27, 1975, and included recording of: pH, color, turbidity, transparency, temperature, depth, and mapping of aquatic vegetation. The sampling stations included the Belle Fourche Ike's pond, Newell city pond, Orman Dam, Belle Fourche River, the Cheyenne River and the confluence of these two rivers.

FLOODPLAIN INTERPRETATIONS FOR BELLE FOURCHE AREA

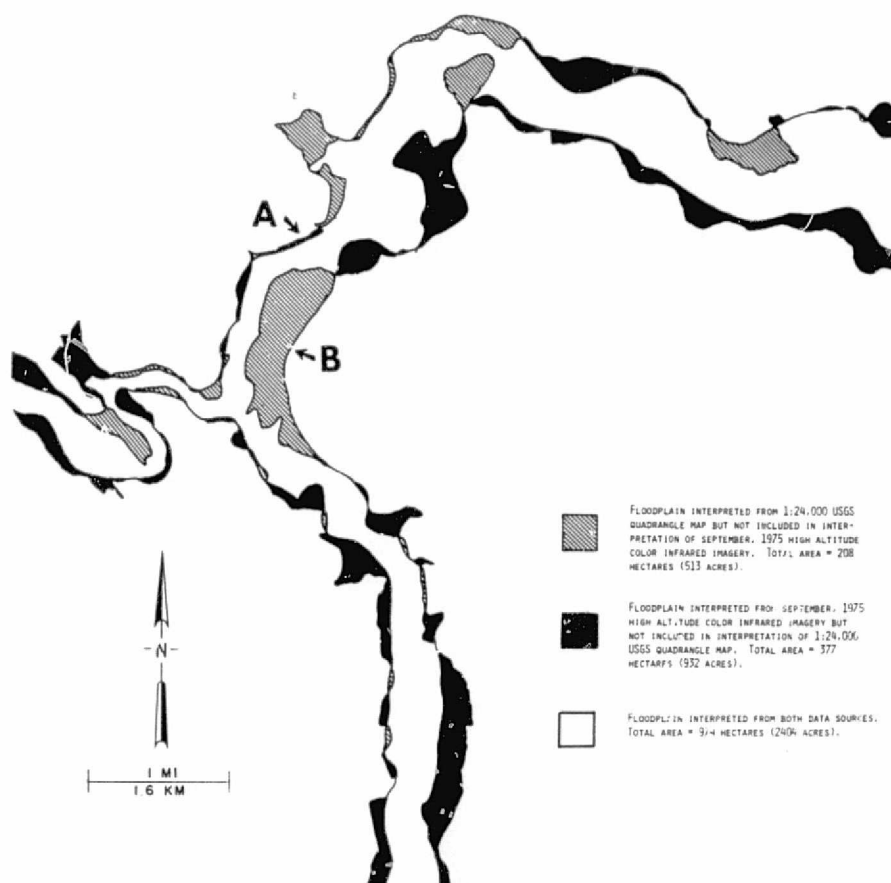


Figure 25. Floodplain interpretation for the Belle Fourche Area. Aircraft imagery remotely assisted in delineating floodplains in areas where the slope of the land was less than .0075, B. Areas of steep slope, A, were comparably interpreted from contour maps and aerial photography.

Fish display a variety of other preferences and tolerances for water bodies that can be measured in terms of dissolved oxygen, alkalinity, ammonia, Ortho phosphate, total phosphate, dissolved solids, nitrate, chloride, and sulphate, as well as the characteristics gathered as ground truth. The ground truth data were chosen based on their potential in being detectable on remotely sensed imagery, either directly or indirectly. Obviously the collection of data on many parameters associated with water quality requires considerable time and travel. Standard methods in existence provide very good data. However, it was with the thought that an indication of the parameters considered "most visible" or at least closely associated with visible perception would enhance the overall management planning effort. It should be emphasized that the interest in applying remotely sensed data was not to replace existing standard methods but to identify the potential of its applicability.

It is important that water quality ground truth measurements be made as concurrent as possible with overflights. A major problem occurred in coordinating the NASA missions with water sampling. Several times when agencies were notified that the flight was to occur, the mission was cancelled due to weather conditions. This created some frustrations for the cooperating agencies helping to collect ground truth. On the day of the RB-57 overflight, cloud cover was still a problem and water samples were not taken, under the assumption that the flight was cancelled. However, samples were collected a few days later, concurrent with the low altitude RSI flight. With ground truth data collected, a period of three months passed before the high altitude imagery was in hand. In most water quality monitoring programs, such a delayed delivery would be unacceptable due to the need for prompt reporting.

Participating agencies found that water quality parameters are not easily interpreted from aerial photography. Certain types of data of interest to the various state agencies (pH, temperature,

dissolved solids, BOD, COD, etc.) are not directly visible in water. Previous studies (17, 18) report that, under certain conditions, these parameters can be statistically related to film densities. Such variances are most likely based on complex relationships between the "invisible parameters" and the sometimes visible (turbidity, suspended solids, algae growth) water quality constituents which can be recorded on film. Establishment of such relationships require extensive ground truth data collection. Vignetting, sun angle effects, and extensive ground truth requirements indicated that the operational use of remote sensing for water quality monitoring is impractical for Western South Dakota at the present time.

Certain items of interest did develop and may lead to further studies and operational applications. Visual interpretation of surface water from high altitude imagery indicated that surface water bodies are of varying appearance. The apparent differences in water quality of these stockdams was not addressed but may be related to the drainage area and its associated land use and soils. Such water quality differences may be detected using Landsat multi-spectral imagery. Surface water so analyzed might then be classified into cursory quality categories, as well as size and relative permanence. It might also be possible that, knowing the relationship between hydrologic and physiographic parameters of surrounding drainage basins as they related to general water quality, river basins might be mapped to provide planners an indication of optimum locations for stockdams or other water-collection reservoirs.

The ability to measure apparent changing water quality on Landsat at a cursory scale is demonstrated with the images of the Belle Fourche Reservoir in Figure 26. The reservoir was imaged every month from May through November. At the beginning of the growing season, the reservoir was full and the inlet canal was dry. The only input to the reservoir system was from the north through natural drainage of Owl Creek. By mid-June turbidity appears to be developing within

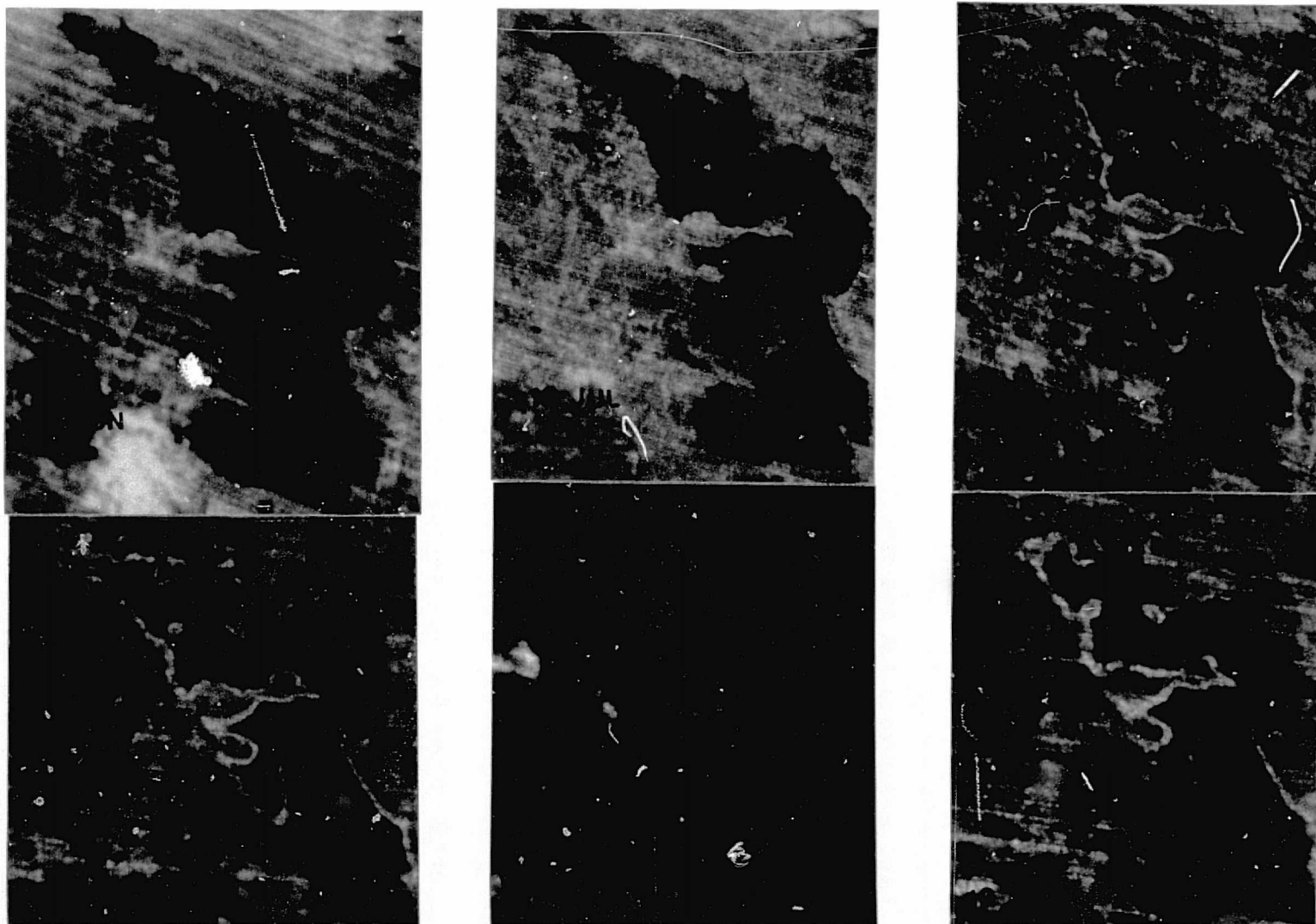


Figure 26. Belle Fourche Reservoir as imaged by the MSS standard false color composite from June through November, 1975. The apparent changes in water quality might be related to Reservoir input, (scene ID. June 12, 5054-16504; July 18, 5909-16483; August 23, 5126-16462; September 1, 2222-16595; October 25, 2276-16593; November 12, 2294-16591).

the water and can be seen developing near the inlet canal. By July the lower half of the reservoir has changed in apparent quality and by the month of August, it appears that approximately three-fourths of the reservoir has been affected. In September, the level of water appears to have dropped and the shoreline receded. The water in the Reservoir appears to be clearing. October and November show further reduction in surface area. Such water quality and surface-like changes are of potential interest to irrigators, stock owners, and fisheries personnel. The data might also assist in locating water quality sampling stations to insure collection of representative data. Presently such procedures are not established, and present operational use of Landsat data in Western South Dakota water quality monitoring programs is minimal.

Mountain Pine Beetle Activity

The situation of intensive pine regeneration and wildfire reduction in the Black Hills has resulted in a heavily-stocked forest. This condition has undermined the vigor and health of the forest resource. This lack of vigor and health contributes to devastating insect infestations such as the present mountain pine beetle epidemic.

Brief comments describing the cycle of the mountain pine beetle will clarify the scope of the current beetle epidemic. Free flying swarms of the adult insects leave pines infested and dying in late July and August. These seek out living pines and "strike." A healthy pine will "pitch out" the attack but a tree with low vigor will not possess enough pitch to deter the attack. Infested pines serve as hosts for the beetles and are killed in the year following the "strike." Adult free fliers again merge to swarm again in July and August. During the infestation the pines fade in color and can be spotted by ground crews with identification becoming more pronounced as the year progresses. The green pines change to a brown color or "red top" in the second year. Early identification of new strikes allows for marking and mapping for treatment crews. Treatment is given

by cutting and removing, cutting and burning, or by applying chemicals, and must be completed prior to the July following the "strike" to remove the host material containing beetle larvae.

June color and color infrared imagery revealed some potential for interpreting large infestations through a process of comparing images (color and color infrared). There is a need to identify new hits in late fall to speed up ground crews. Interpreters did not think this was possible, however, since the June imagery revealed only traces of the larger infestation that had progressed to a definite fading condition. This observation of the shortcomings of color infrared photography is also shared in a paper "Forest Stress Detection" printed in USDA Forest Service Research Paper PSW 112-1975, pp. 44-63. This paper was included under the overall title of "Evaluation of ERTS-1 Data for Forest and Rangeland Surveys."

The remaining option is to interpret imagery for "red tops" which identify the areas from which the beetles have recently flown. Ground crews could then be more selectively dispatched in their search for new hits. It would be more efficient to work on a data base of new hits within 30 days from the time the "red tops" could be determined from September imagery. The imagery, three months preceding the beetle flights, is too late for effective ground action on new hits or on last year's red tops. The best time period for color and color infrared films for mountain pine beetle detection appears to be during August or September, using identification of red tops rather than new hits. As shown in Figure 27, a September low altitude color infrared print, the infested trees appear green. The "red tops" of previous years' infestations are seen as dark green and the lighter green areas are indicative of pines fading in color towards the end of the pine beetle life cycle. These trees will then be "red tops" the next year.

In summary, the detection of new beetle "hits" was negative but indirectly the new infestation might be more effectively located by ground teams working out from the most recent red top areas. Turn

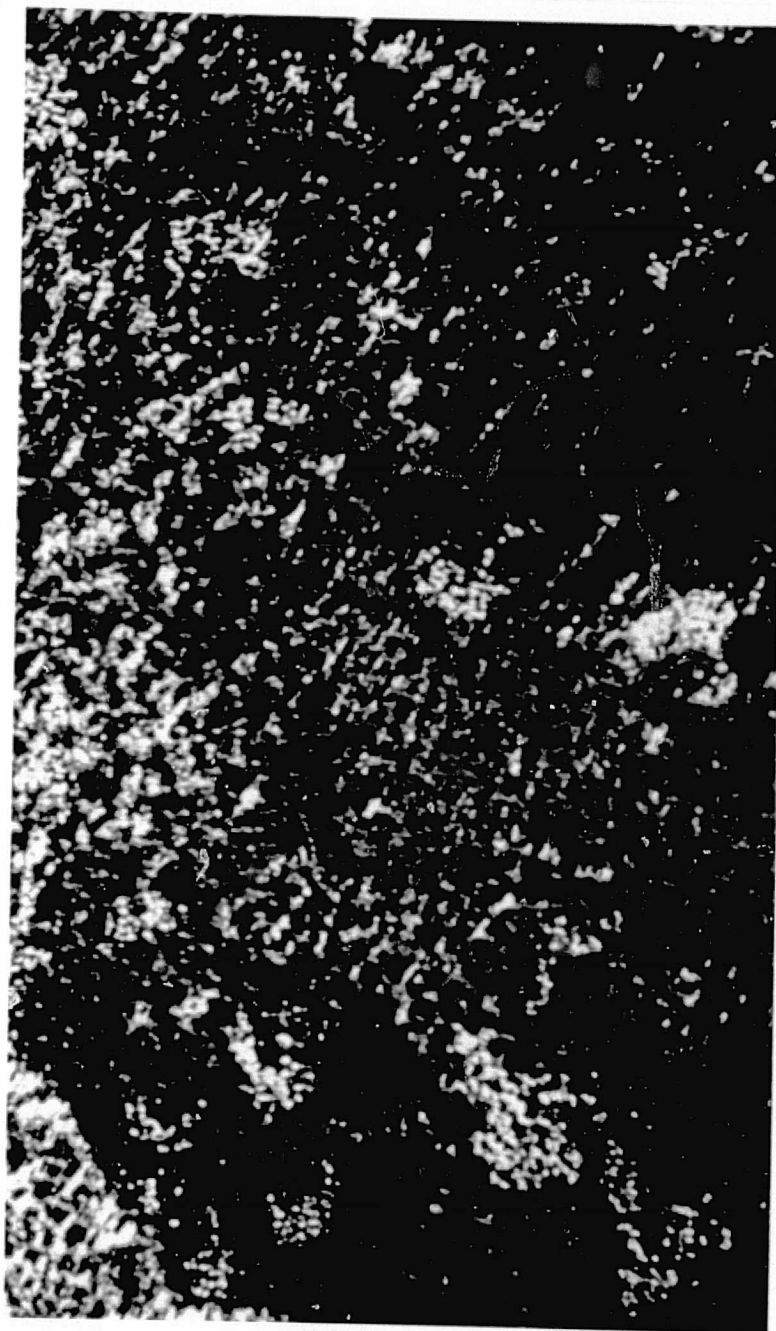


Figure 27. Low altitude color infrared imagery. September 9, 1975, with Mountain Pine Beetle infested trees annotated.

around time on imagery should be no less than 30 days. Interpretation of June high altitude imagery did not allow adequate interpretation of infested areas. September high altitude imagery was adequate but, considering the somewhat confined areas and detail required, low altitude imagery is preferred.

The dimensions of infested areas seldom exceed a ground area comparable to 1-2 Landsat pixels. When an attempt was made to interpret Landsat visually, no data were observed. Digital analysis of July and September CCT data did not result in much success as selection of classifier training areas was severely restrained due to the small areas.

Canal Seepage

Forecasts of available water resources have substantial economic value to irrigation farmers who must plan upcoming crop seasons. The value of good forecasts increases as fresh water becomes more scarce. It has been stated that half of the irrigation water is lost between the reservoir and the crop in the field, most apparently lost through seepage from canals and ditches (18). Remote sensing of standing water and wet/dry boundaries would appear to be an ideal method of detecting and monitoring these leaks and/or breaks by utilizing a change in wetlands or vegetative cover adjacent to the waterways as indicators. Site 2, Figure 1, was selected to examine the potential for detecting leaks in a canal system via standard remote sensing techniques. Imagery of the specific canal area is shown in Figure 28, a high altitude near-infrared print of June, 1975. Neither high nor low altitude June imagery were of exceptional value for detecting canal leaks as water was just beginning to enter the canal system. By September, the canals had been flowing full for about four months. Ground surveys indicated seepage areas to be located as numbered in Figure 28. Area 1 is seen in the ground truth photograph of Figure 29. Note the presence of cattails. Standing water, approximately 15 cm (5.9 inches) deep, was present in this area. Another smaller

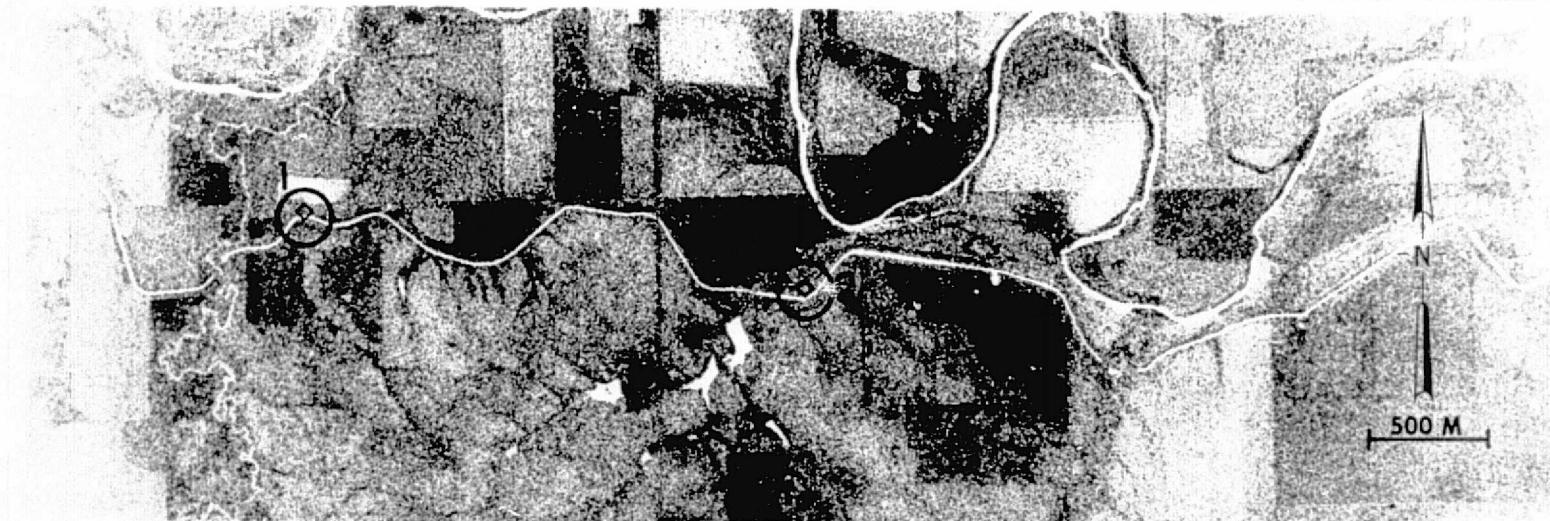
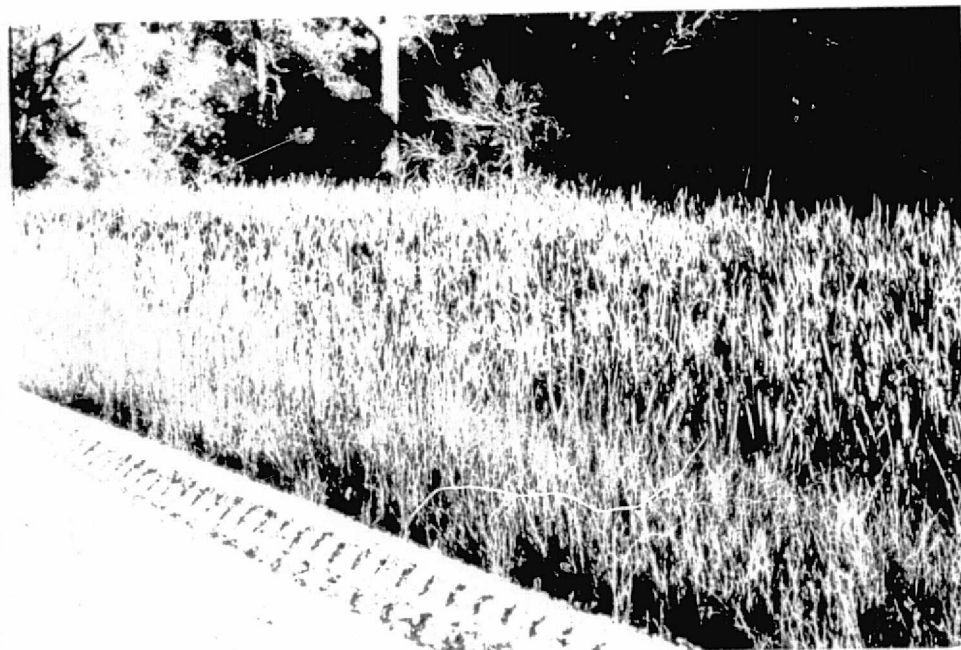
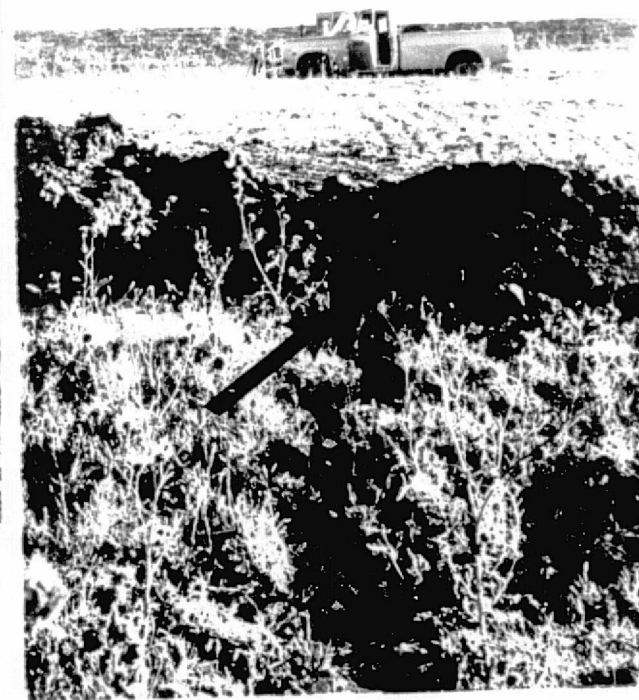


Figure 28. June 25, 1975 RB-57 data over the irrigation canal being supervised for leaks. The 80 mm Hasselblad near infrared data proved to be of minimal use in detecting canal problem areas. Areas one and two are areas of standing and running water, respectively, and are also seen in ground photographs in Figure 29.



a



b

Figure 29. Ground truth photographs of apparent canal seepage areas 1 and 2 (Figure 28) a and b, respectively. Notice the cattails in the standing water of (a) and the location of a flowing leak in (b).

seepage area was also found. Ground level inspection of these seepage areas did not ensure that the wet areas were due to canal leaks but verbal confirmation from a local irrigation district worker indicated a probability that the seeps were canal-fed. A large leak in the canal existed at a third site and is located as point 2 in Figure 28. The ground truth photograph of the leak (Figure 29) records a continuous flow of water emanating from a hole in the canal wall. Interpretation of low altitude imagery indicated that the large leak was not interpretable. There were no obvious vegetation signatures to help detect the leakage water, possibly because new construction in the area removed existing vegetation and new growth had not yet developed.

In the seepage areas, hydrophytes predominated the standing water areas. A trained interpreter would be able to recognize such wetland areas on low altitude color infrared imagery. From an operational standpoint, it does not appear simple photo analysis by relatively untrained interpreters can detect canal leaks from a color infrared film for this area. Possible greater attention to data timing and use of thermal data would allow for more easily interpreted data.

Crop Identification and Irrigation Delineation

The major cropping area within the Belle Fourche River Basin is that within the Belle Fourche Irrigation District, Figure 1. Study site number 6 was selected by participating state agencies as the location for evaluation of remote sensing for operational crop identification efforts because of the variety of crops. Initial efforts concentrated on obtaining ground truth data on which to base subsequent data analyses. Agency representatives collected crop identification information June 5 and 6 and September 9, concentrating on 91 fields within the flight line.

These field patterns were easily identified on the June and September low altitude aircraft imagery. Visual identification of crops on low altitude imagery was attempted and was not successful. Without the benefit of time-sequential data, total crop identification becomes difficult and very reliant on the date of data collection.

For example, if data are collected too early in the growing season, the fallow fields will appear the same as planted corn fields, etc. Too late in the growing season and a matured corn field would appear similar to a ripened small grain field. The apparent resolution of low altitude data might allow distinction of some of these differences by interpretation of physical indicators such as cultivating patterns. But, extrapolation of such interpreted low altitude data to large-area situations would probably induce the same type of estimation errors already present in existing data sources.

High altitude data collected over this area were cloud-covered during the June flight, rendering it useless. The September high altitude data were too late in the growing season to be of value as a single data source.

Landsat data from every month from May through October were analyzed. Color composite print enlargements of the test strip were visually inspected in an attempt to observe any interpretable changes in reflectance patterns. It was obvious that differences exist as the growing season progressed; however, simple delineation of known field boundaries was impossible except in a few isolated cases. Even if all boundaries could be determined for a large agricultural area, multi-date data would be required to monitor the individual fields during the crop calendar. Such an effort, if done manually, would produce extreme data handling difficulties.

Computerized data handling was then investigated to interpret large areas and to register data for such large areas (using DIRS) to conduct time-sequential reflectance monitoring. July 27, 1975 CCT data, as rectified by DIRS, were selected for three designated survey areas within the test strip. A histogram of Landsat CCT MSS data allowed for the selection of shade-print levels to maximize contrasts in line printer maps. The latitude and longitude boundaries of the three areas were determined via the 1:24,000 USGS Quadrangle maps and line printer maps were prepared. More fields were identified on this

form of Landsat data than on the prints; however, of the total of 91 individual "ground truthed" fields, only 18 were successfully located on MSS 5 or 7 printouts of both July and September CCT data. There was an inconsistency, in terms of size, in the detection of fields. There were enough doubts in the location of potential training data fields that further analyses were not conducted. In theory, if sequential CCT data were used in conjunction with the registration capabilities of DIRS, each field in a Landsat scene could be automatically monitored throughout the growing season and its crop type predicted. The procedure appeared to require considerable research and development and was not considered to be a presently operational method, but rather was recommended for further research.

Aspen Delineation

Within the Black Hills, the dominant ponderosa pine has encroached upon the less competitive aspen species. At the present time, Black Hills aspen has little commercial (or other) value. The stands are presently in a stagnated growth condition. The South Dakota Game, Fish, and Parks Department is involved in studies of the management potentials of aspen. For the past two years, GF&P has addressed the potential for improving the habitat available for ruffed grouse through experimental prescribed cutting designed to remove decadent aspen stands and generate a new cycle of aspen growth. This action is based on a 1974 tour of the Black Hills by Mr. Gordon Gullion, a noted wildlife biologist and recognized grouse expert with the University of Minnesota. His recommendations to GF&P for enhanced ruffed grouse habitat management were based on 18 years of experience with grouse in the northern U.S. (19).

In Mr. Gullion's opinion (shared by the U.S. Forest Service and GF&P) the general aspen situation is one of old decadent stands no longer competing but succumbing to invasion of ponderosa pine. Gullion expressed concern that within the next decade or two, the potential for grouse management would be lost along with the decrease in aspen. He

further observed that with certain cutting prescriptions and the subsequent regeneration of new aspen from root stocks of the parent clones, aspen could be managed to produce as many grouse per acre as any part of Minnesota.

A recently proposed GF&P study is designed to investigate the management of aspen for ruffed grouse habitat. Potential results of the GF&P study include a ruffed grouse game management plan established in the manner of management plans for other game species in South Dakota. For such an overall plan to be successful, accurate base data on the present distribution of aspen are required.

Game, Fish and Parks personnel have also been involved in a research study which is evaluating aspen as a livestock feed supplement. Researchers have reported that all aspen-containing rations were superior to the control ration in daily gain and feed required per unit weight gain. Preliminary conclusions indicate that aspen could serve as a major feed component if its known nutritional deficiencies are corrected (20). Potential private industrial development of aspen harvesting within the Black Hills is considered by GF&P officials as a distinct possibility. Knowledge of the location of harvestable aspen and monitoring of harvesting activities on a regular basis would contribute greatly to the management of aspen for livestock feed according to GF&P officials. To commercially launch this or any other use determined as potentially feasible, a reliable inventory of the aspen resources is needed.

Initial efforts to inventory aspen centered on distinguishing between coniferous and deciduous trees. Visual interpretation of 1:250,000 winter Landsat prints was conducted. It was thought that, in a forested area, the tree canopy would have a different reflectance than the snow-covered non-forested areas, allowing for a visual interpretation of the forested areas. Negative prints were chosen for the interpretation as they are one step closer to the original and the interpreter expressed preference to mapping the white "highlighted"

forested areas as opposed to the normally dark forested areas. With cross-referencing to high altitude aircraft imagery, the interpreter was able to distinguish forested, mixed and non-forested areas. This forest boundary interpretation was then superimposed on a summer (27 July) color composite print to allow distinction between coniferous and deciduous trees. Within these forested areas there are essentially two shades of red: a very dark red usually associated with coniferous stands and a brighter red associated with non-forested grassland and deciduous trees. However, the effect of forest density confounded the interpretation. Distinction between aspens and areas of thin pine with a thick grass undergrowth was extremely difficult to accomplish on the 27 July imagery.

Digital analysis of the 27 July data was then tried. A CCT for Landsat scene 2186-17004 (27 July) was obtained. A representative area was selected from high altitude aircraft imagery and the approximate CCT pixel coordinates for the sample area were determined. Initially, MSS 7 data were removed from the tape and displayed via the line printer. Comparison of this "raw" MSS 7 data with aircraft imagery was conducted to manually select CCT reflectance levels which would correspond to grass, pine, and aspen. A level was selected for each of the three classifications and a line-printer map was generated. Visual inspection of the level-sliced MSS 7 data revealed that grass and thin pine were still being misclassified as aspen.

The NASA provided Digital Image Rectification System, DIRS, (see Data Management Section) and a RSI classification program called "K-class" were then employed to determine if a statistical relationship could be developed using MSS bands and selected training areas. Training areas consisting of pine, thin pine, aspen, and grass were designated from high altitude aircraft imagery and selected ground truth. The area included sufficient samples to allow K-class to classify the data into three basic categories of pine, aspen, and grass. The K-class processing of CCT data produced a more reliable

classification with less confusion among thin pine, grasslands, and aspen. Figure 30 is the aspen interpretation of high altitude color infrared film for the area initially digitally analyzed for Landsat CCT's. Notice that not only are there few large aspen stands but numerous smaller stands throughout the area. The stand marked "A" can also be seen correctly identified in the K-class generated map of Figure 31. Here again, one can see a few large aspen stands and numerous smaller stands throughout the forest. The map of Figure 31 is unrectified Landsat data which makes evaluation of spatial accuracy difficult.

Mid-summer is not an optimum time for the collection of data to be used in aspen interpretation as the differences between aspen and grasslands are relatively subtle. Such conclusions were also reported by Driscoll (21). The July data were processed because of availability and to test procedures involved. Comparison of the June and September high altitude aircraft imagery shows the distinction between aspen and grass is much more pronounced in the September data than in the June data. In September, the grasses have apparently dried and their reflectance changes considerably. Dried leaves of grasses along with the withering, folding, etc., reduce leaf surface area and IR reflectance and increase in visible reflectance. The increased visible reflectance changes the total reflectance (i.e. color balance) of the grasses. However, the aspen leaves are still as "green" in early September as in June. The distinction between grass and aspen is, therefore, enhanced. A cloud-free September 1, 1975 Landsat scene (2222-16595) over the Black Hills was therefore selected for evaluation.

The DIRS program was also used on the September CCT. Aspen, mixed aspen-pine, grass and pine training areas were selected by reviewing high altitude imagery and selected ground truth information. The supervised classifier, K-class, was used for digital interpretation on three townships. Figure 32 is a high altitude aircraft



Figure 30. Aspen interpretation of high altitude color infrared (June 1975) imagery. Interpretation scale was 1:32,000. The outlined interpreted area corresponds to the area digitally analyzed from Landsat CCT data. Note the aspen stand marked "A".

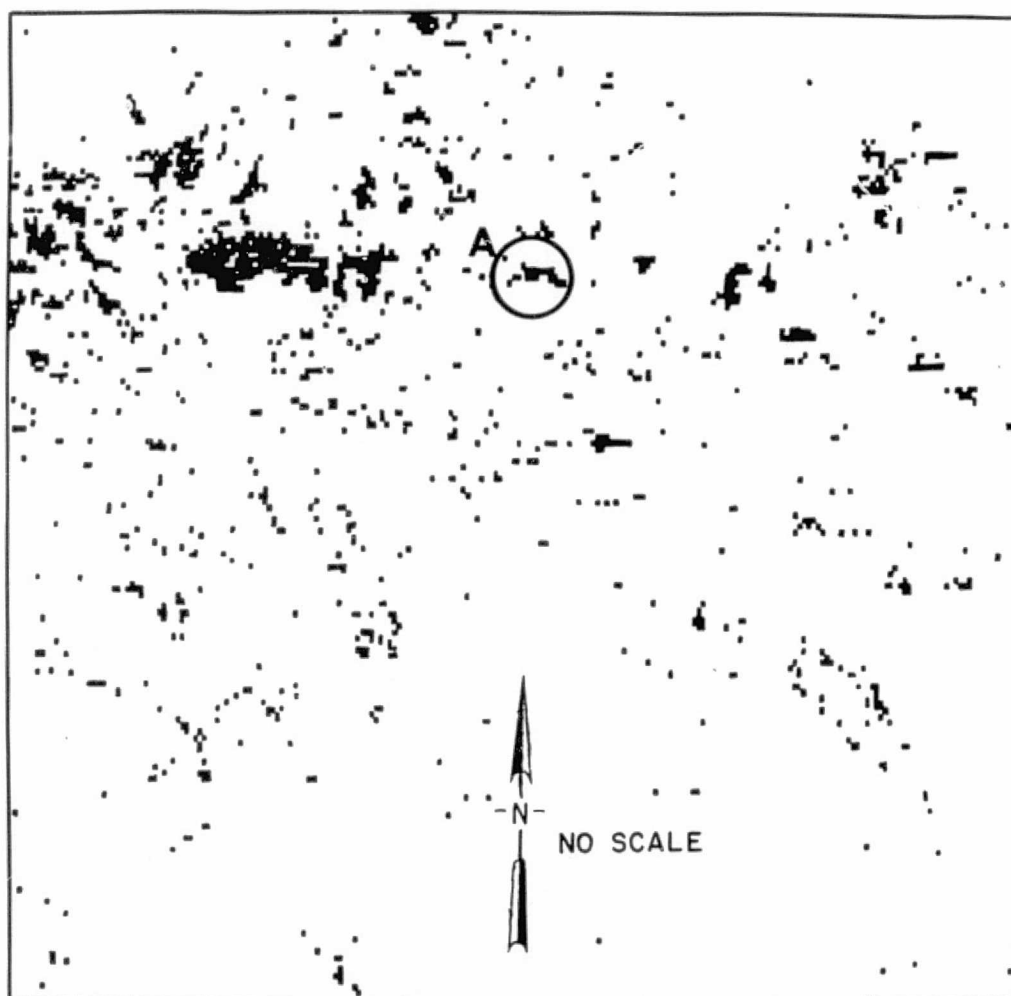


Figure 31. K-class aspen interpretation of 27 July 1975 Landsat CCT data. Note stand "A" has been correctly identified.



Figure 32. High altitude color infrared (June 1975) imagery of township T4NR5E as interpreted for aspen. Note stand "A" (same as that in Figures 30 and 31) and the numerous small aspen stands.

interpretation of aspen and mixed aspen-pine for T4NR5E. Again, the interpreted aspen stand referred to as "A" in Figures 30 and 31 can be seen along with numerous smaller stands. A U.S. Forest Service map of the township was obtained and the aspen interpreted from this map is shown in Figure 33. Notice the absence of stand "/". Also, notice the absence of the smaller stand of aspen. The K-class interpretation of DIRS-rectified September Landsat CCT data is seen in Figure 34. Similar interpretations were conducted for T4NR2E and T5NR2E, Figures 35 and 36 respectively.

Visual interpretation of all three townships was conducted at 1:24,000 on the ZTS. To assist in evaluating the various data sources, all maps were reduced to the scale of U.S. Forest Service Type 1 Maps (1:32,000). Visual "analog" interpretations were manually converted to a cellular base of .4 hectare (1 acre) cells for direct comparison with Landsat data. Comparisons listed in Table 19 were conducted using June high altitude aircraft imagery as the data base. The September 27 high altitude imagery was too late in the season to be considered as an effective ground truth data source. Ground level sampling verified that the aspen leaves were already in the stages of changing color at the time of data collection.

There is a difficulty in measuring the accuracy of Landsat CCT interpretations. Because of the human factor in visual high altitude aircraft interpretation, areas of mixed aspen-pine are not easily interpreted with consistency. In areas of heavy pine, a mixed area might not be interpreted the same as if it were located in areas of solid aspen or grass. Comparisons between Landsat and high altitude aircraft interpretations would reveal these inconsistencies but it was felt that re-interpretation by the same interpreter would be too biased to be of any value. Selection of ground-studied K-class training areas (with input from GF&P to allow accurate identification of training areas) and identification of the training areas by latitude and longitude would allow for further refinement of mapping

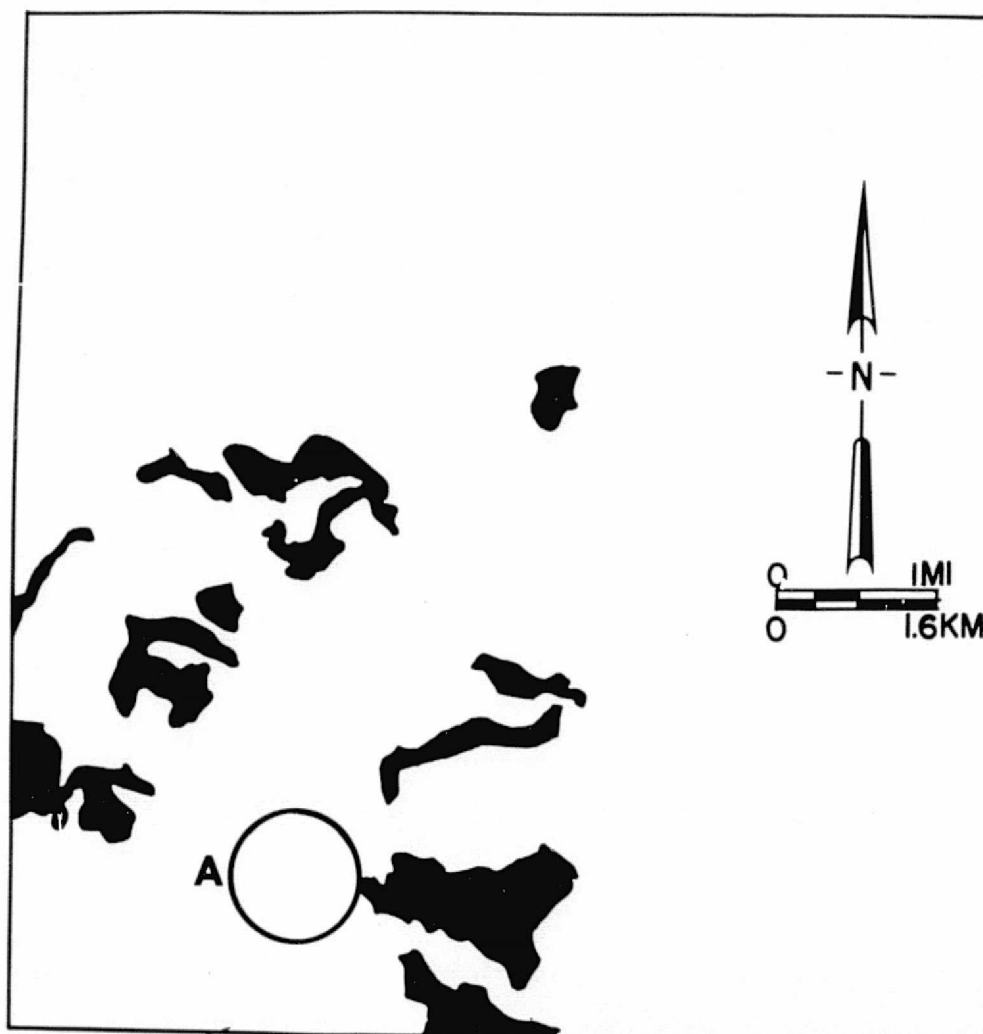


Figure 33. Aspen data interpreted from U.S. Forest Service map of township T4NR5E. Note the absence of stand "A" and the lack of smaller aspen stands throughout the area.

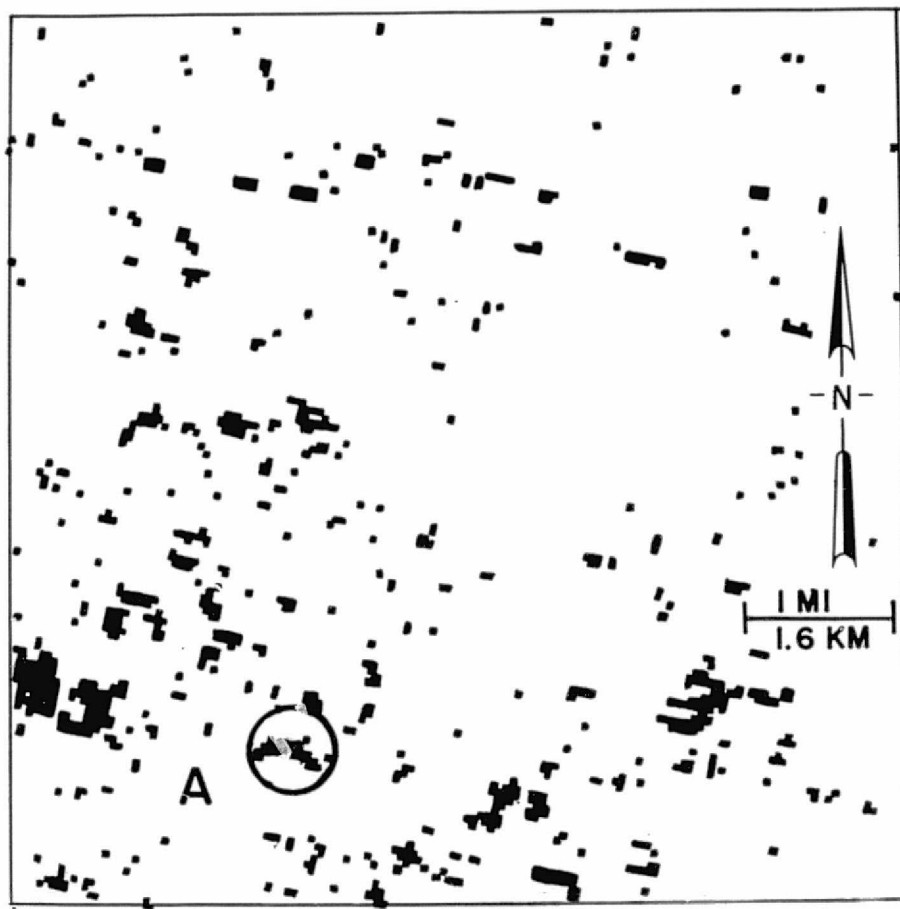


Figure 34. Combined use of DIRS, K-class and plotter provided this aspen map for T4NR5E using Landsat CCT data. Stand "A" is easily recognized.

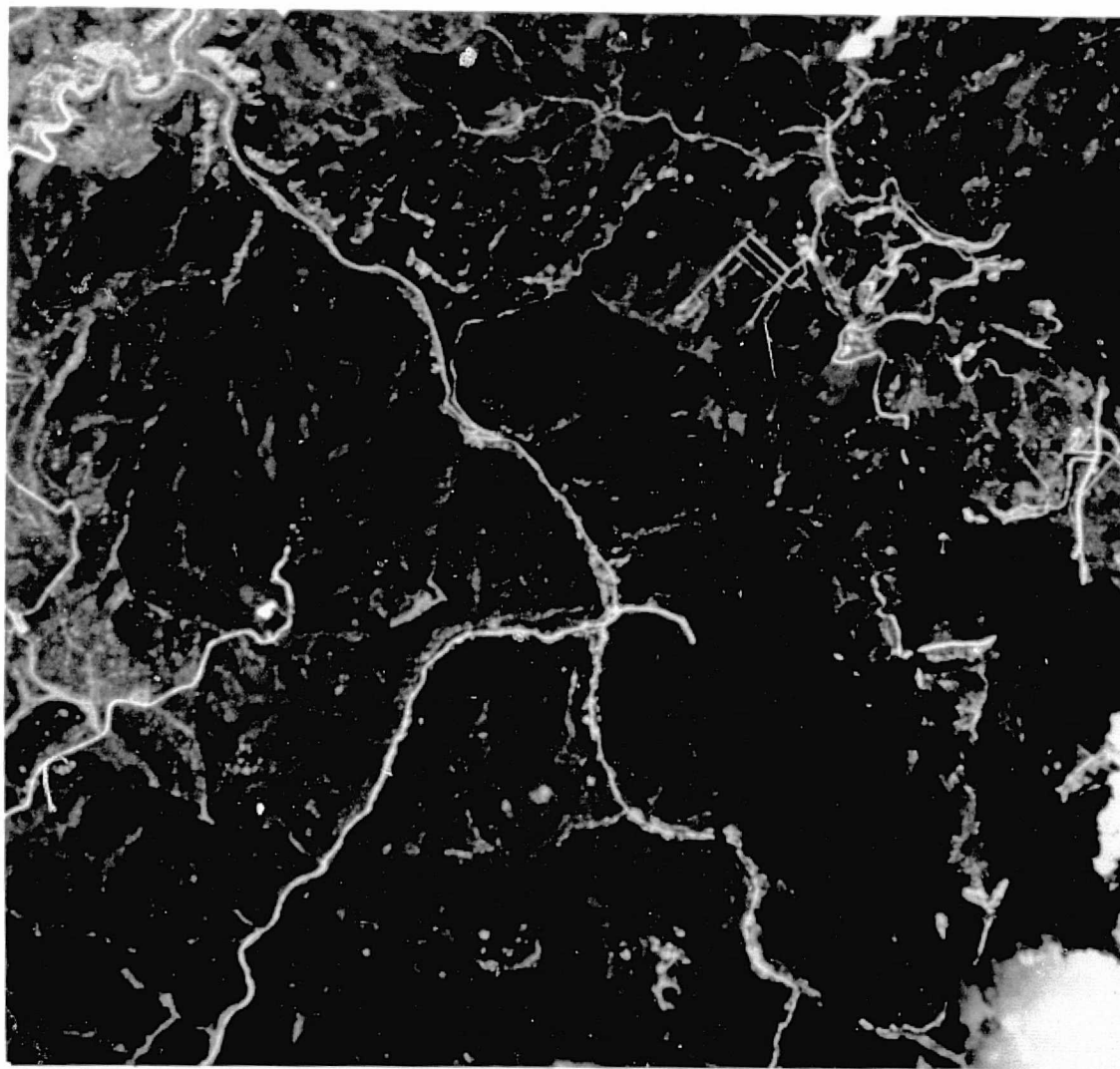


Figure 35. June 1975 color infrared print from high altitude aerial photography of T4NR2E. Various overlays include Landsat digital analysis, visual RB-57 interpretation and the U.S. Forest Service aspen map for the area.

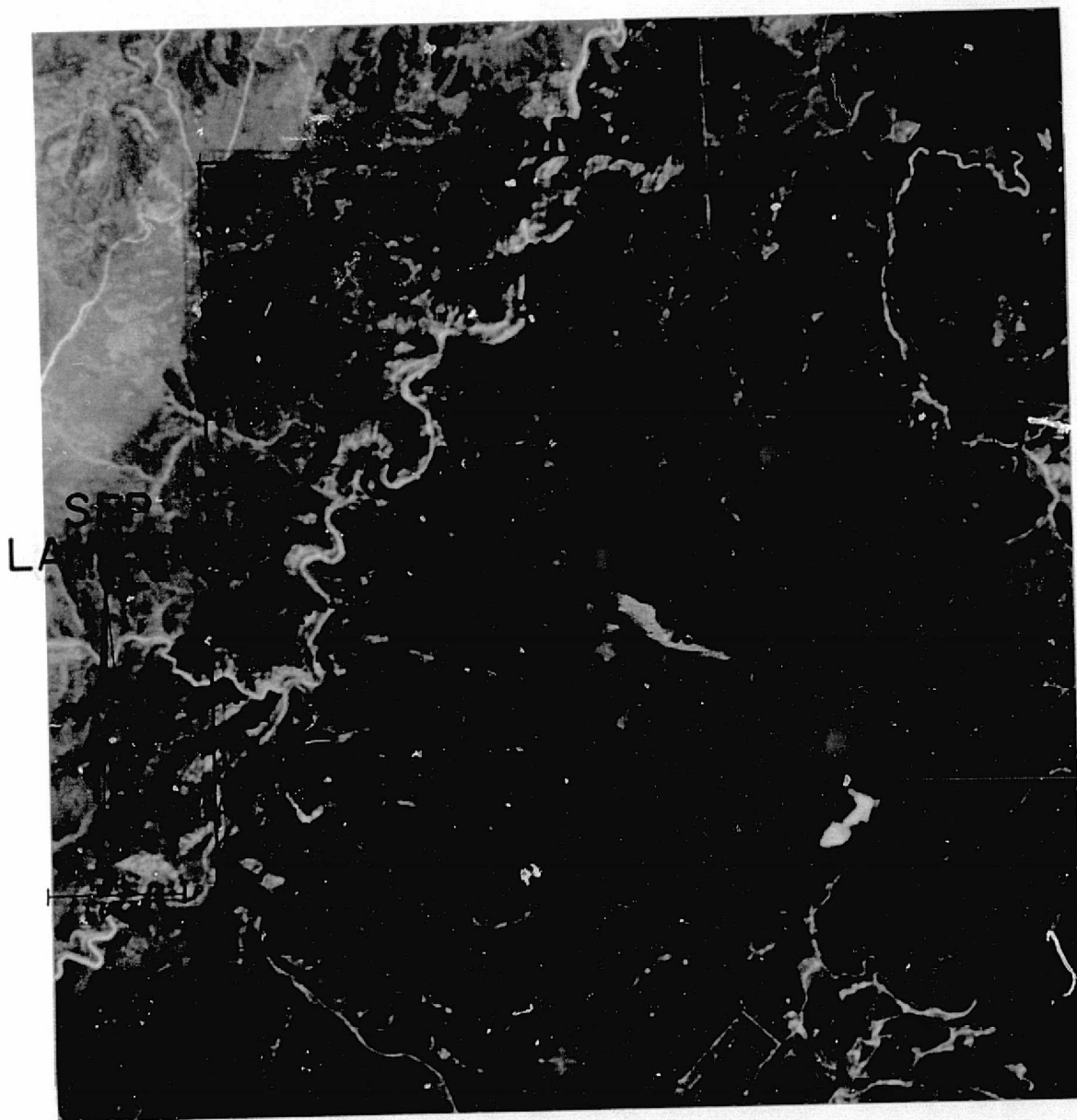


Figure 36. June 1975 color infrared print from high altitude aerial photography of T4NR2E. Overlays include Landsat digital and RB-57 visual. No U.S. Forest Service aspen map was available.

procedures and would offer permanent "benchmark" areas on which to base subsequent aspen monitoring effects.

TABLE 19. ASPEN CLASSIFICATION ACCURACIES AS COMPARED TO JUNE HIGH ALTITUDE AIRCRAFT VISUAL INTERPRETATIONS.

Source	Percent Aspen as Aspen	Percent Other as Other	Percent Average
T4NR2E:			
LANDSAT	49	92	70
USFS	34	97	65
SEPT. AIRCRAFT	26	97	61
T5NR2E:			
LANDSAT	62	84	73
USFS	--	--	--
SEPT. AIRCRAFT	--	--	--
T4NR5E:			
LANDSAT	45	97	71
USFS	41	95	68
SEPT. AIRCRAFT	47	98	72

To demonstrate the potential of using Landsat data, the Belle Fourche River Basin was mapped for aspen. Due to processing limitations in the DIRS routine, the area of interest, 98,000 hectare (245,000 acre) forested area within the River Basin, was subdivided into three strips each approximately ten minutes wide (longitude). The Landsat CCT data were extracted and rectified using the same DIRS parameters used in processing the three individual townships. The K-class training data used in the processing of the three townships mentioned previously were used in the classification of this much larger area. With all user-specified and raw data variables the same, the resultant aspen map generated for the area is seen as Figure 37.

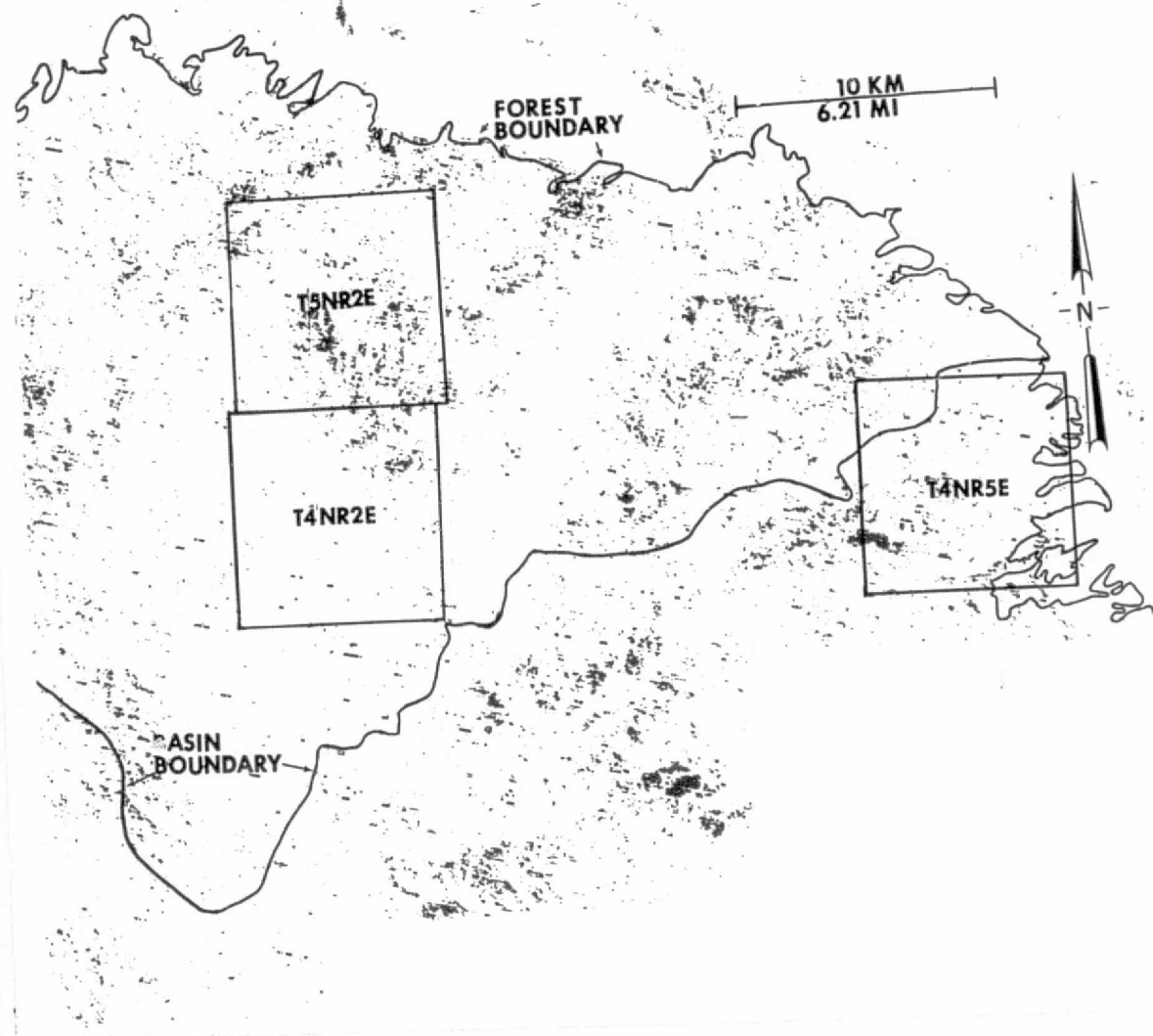


Figure 37. Preliminary map of the aspen within the Belle Fourche River Basin using September 1, 1975 Landsat data, DIRS, and K-class for data extraction.

IV. DATA MANAGEMENT

Digital Image Rectification System

One of the major advantages of rectifying Landsat CCT data is the resultant potential for sequential computer data assessment. For example, the digital analysis of rectified CCT's could permit automatic comparison of surface water inventories at different time periods and sequential monitoring of crop reflectance and knowledge of area crops which would assist in accurate areal crop identification. The potential for automatic mapping and monitoring of resources (such as aspen) is within the possible uses of rectified Landsat CCT data. Necessary for such work is a method of reducing the distortions inherent in the CCT's as supplied by EROS. NASA has developed a rectification program package specifically for "correcting" Landsat data. The Remote Sensing Institute obtained the NASA-developed programming package called Digital Image Rectification System (DIRS). DIRS was designed to operate on digital Landsat MSS imagery and to cartographically correct the data to a Universal Transverse Mercator (UTM) grid system (22).

Selection of approximately twenty Ground Control Points (GCP) per scene is recommended. The GCP's are geographic or physiographic landmarks (e.g. airport runway intersections) which can be easily found on the Landsat image and on reference maps (1:24,000 USGS Quadrangle). After the GCP's are selected and the approximate pixel coordinate for each GCP is established, DIRS produces a shade print (Figure 38) of the GCP. The print is used for verification of the GCP location. MSS pixels are numbered on all sides of the shade print and the GCP coordinate is precisely located using this information. The pixel coordinates are used as input for the next DIRS step which provides for expansion of the MSS data at the GCP site. A series of 3x3, 5x5, and 10x10 cubic convolution expansion line-printer maps, Figures 39, 40, and 41 were generated. These maps were used in conjunction with the 1:24,000 USGS Quadrangle maps to more accurately correlate the UTM and pixel coordinates. In some areas of western South Dakota there are no 1:24,000 maps

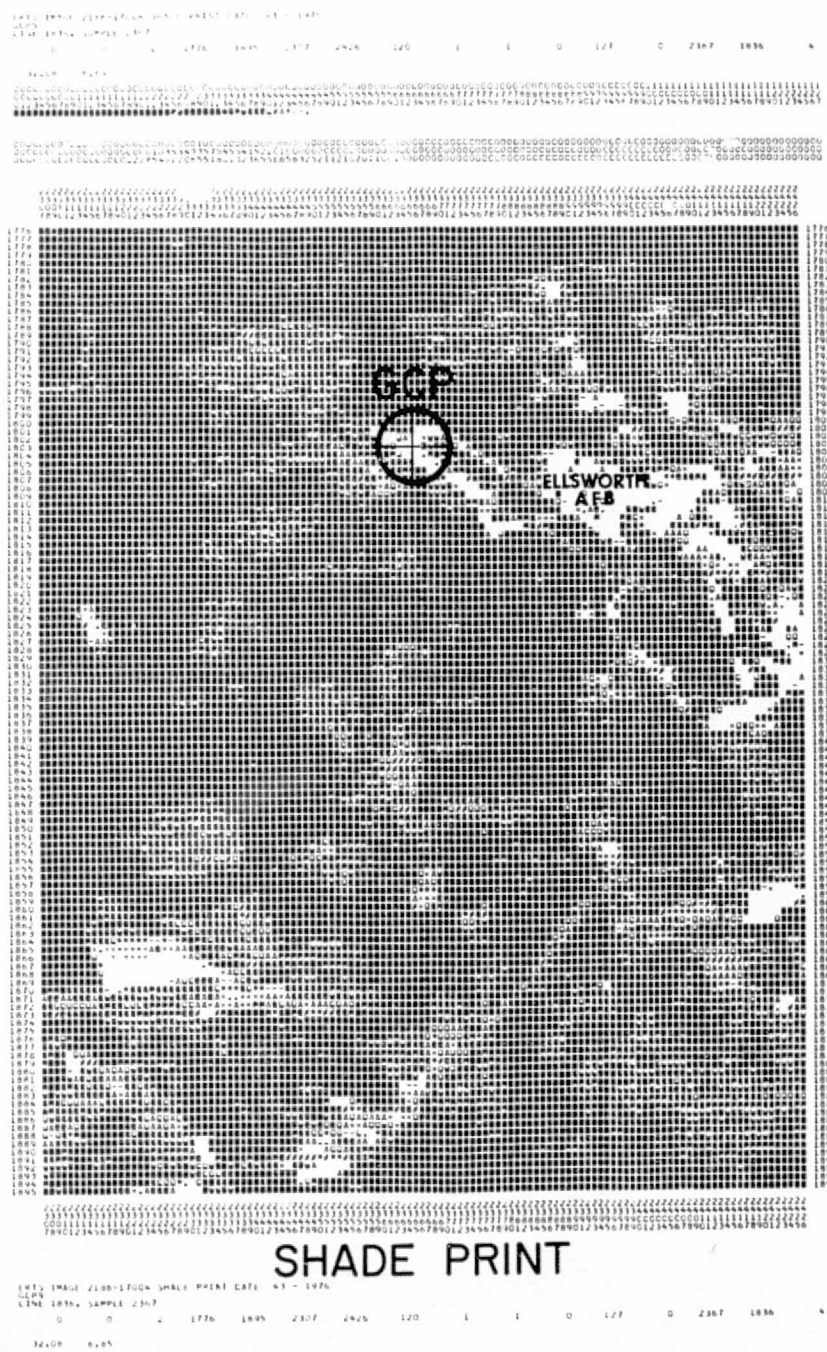


Figure 38. DIRS - generated shade print of a runway intersection ground control point. (GCP).



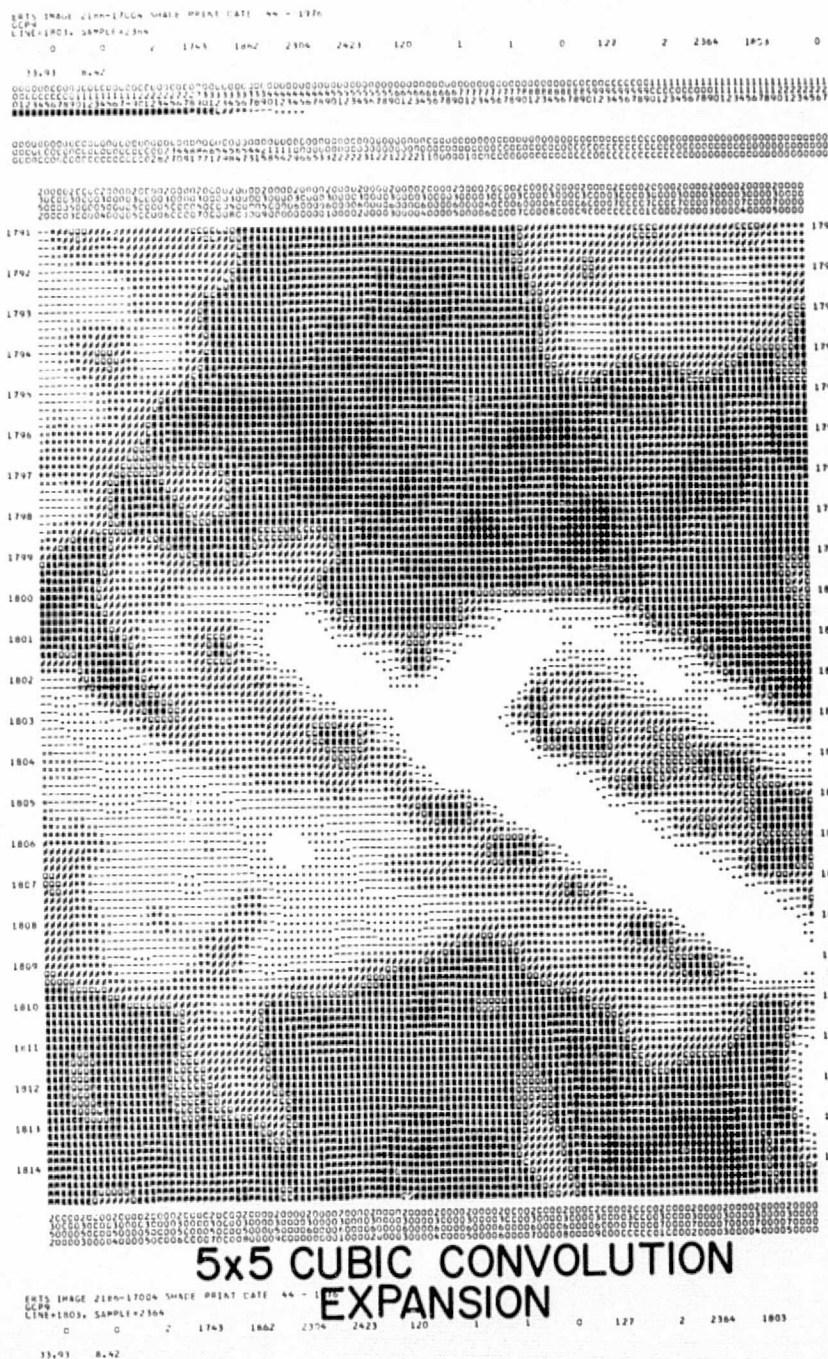


Figure 40. DIRS - generated 5x5 cubic convolution expansion of runway intersection seen in Figures 38 and 39.

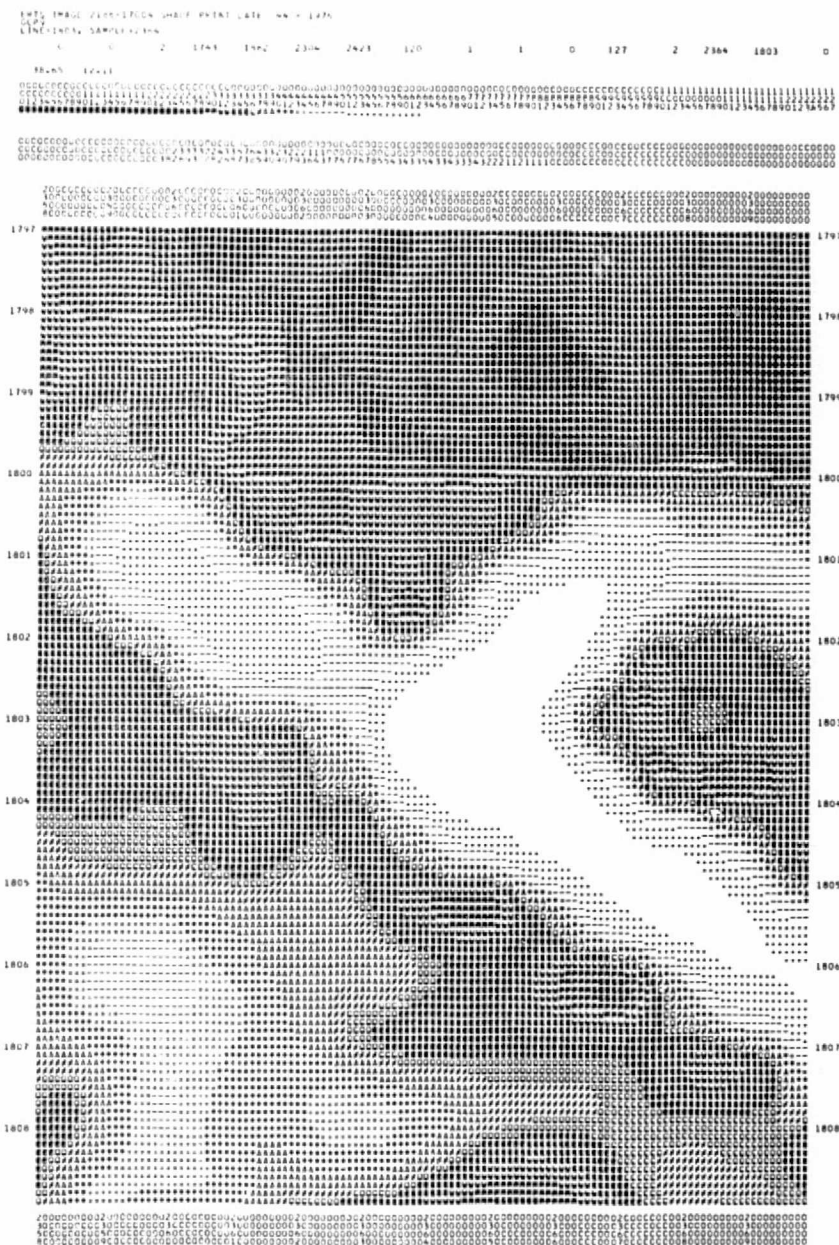


Figure 41. DIRS - generated 10x10 cubic convolution expansion of runway intersection (Figures 38 through 40). Note the MSS pixel assignments (numbers surrounding the expanded data) allow UTM coordinates to be assigned to tenths of a MSS pixel.

available. In other cases, the 1:24,000 maps have no UTM coordinates. These facts must be kept in mind while selecting GCP's. Using the 10x10 expansion and the Quadrangle map, a UTM coordinate is assigned to the GCP pixel coordinate in terms of tenths of an MSS pixel. For example, the GCP pixel coordinate for Figure 41 is 2364.2(X), 1803.4(Y), and the corresponding UTM coordinate is 650,426E, 4,891,064N. Similar procedures are followed for all designated GCP's.

With the coordinate input, DIRS generates data that are used for the rectification of an entire scene or portions thereof. Landsat scenes E-2186-17004 and E-2222-16595 were processed using DIRS. Initial work with DIRS revealed that considerable technician time is required in the processing of GCP's. Selection of points, working with the various printouts and determining coordinates was not a major consideration of the first CCT to be rectified. Subsequent rectification of scenes over the same area allowed duplication of GCP's and associated UTM coordinates. Based on these procedures, approximately five man-days are required for ten GCP's.

One of the major advantages of rectifying Landsat data is the resultant potential for temporal analysis. This overlay capability will allow monitoring of specific points on the ground, on a temporal basis, by permitting pixel-for-pixel overlay in a time-sequential period limited by cloud conditions and Landsat orbit configurations. To evaluate DIRS output for such requirements, a series of geographic accuracy test points has been selected. For inclusion as a test point, an object must be identifiable both on the 1:24,000 Quadrangle map and on the DIRS-rectified output. A point is selected and the latitude and longitude are determined from the base map. A four minute by four minute window surrounding the point is extracted from the CCT and processed using DIRS. Knowing the window boundary latitude and longitude and spotting the test point on the printout allows calculation of the DIRS - generated latitude and longitude by simple scale measurements and ratioing. Registration capabilities were evaluated by

comparing the two rectified CCT data sets in this manner. The geometric accuracy test points evaluated are listed in Table 20. To assist in evaluating the information contained in Table 20, the differences in combinations of latitude/longitude are presented in Table 21.

It should be reiterated that identical GCP's and UTM coordinates were used for the July and September CCT's. There are two basic reasons for this: 1) decreased costs involved in GCP processing, and 2) ability to enhance potential overlay capabilities of the rectified output.

Table 20 illustrates that of the twelve check points, three were considered of questionable value due to difficulty in confidently locating the test point on the printouts. The apparent disparity is not as evident here as in later comparisons. The average disagreement between USGS maps and July and September DIRS - generated coordinates is 87 meters (285 feet) latitude and 159 meters (521 feet) longitude. There is no explanation for the increased error for longitudinal rectification. Using ten GCP's, DIRS will apparently rectify a Landsat CCT to within two pixels of accurate ground location. Table 21 reflects the registration capabilities of DIRS using ten GCP's and two Landsat scenes. Here, the three questionable points have become more pronounced. The registration error is greater for these three points (again in longitude only) than all other points. Including the questionable points in an average, the overlay capabilities appear to be within 49 meters (161 feet) latitude and 38 meters (129 feet) longitude. It appears that using ten GCP's, DIRS is capable of rectifying Landsat CCT data to allow overlay within a pixel. Eight other points were contemplated for evaluation but location of map-related features was unsuccessful.

In the comparison of the aspen classification maps (see aspen section) for the individual townships and for the entire Belle Fourche River Basin, several discrepancies in classification were noted. This was especially evident for T4NR2E. Investigations were undertaken to

TABLE 20. LATITUDE AND LONGITUDE OF GEOGRAPHIC ACCURACY TEST POINTS.

Test Point No.	USGS Base Map		JULY CCT		SEPT. CCT	
	Lat	Long	Lat	Long	Lat	Long
1	44°18'42"	103°35'00"	44°18'44"	103°35'02"	44°18'43"	103°35'00"
2	44°13'26"	103°22'05"	44°13'27"	103°21'56"	44°13'26"	103°02'35"
3	44°09'31"	103°07'12"	44°09'37"	103°07'09"	44°09'35"	103°07'08"
4	44°13'50"	102°41'28"	44°13'57"	102°41'10"	44°13'57"	102°41'10"
5*	44°29'14"	103°11'17"	44°29'09"	103°10'58"	44°29'08"	103°10'54"
6	44°06'49"	103°56'48"	44°06'46"	103°56'49"	44°06'47"	103°56'45"
7	44°15'07"	103°08'56"	44°15'11"	103°08'51"	44°15'08"	103°08'53"
8	44°08'28"	103°35'21"	44°08'31"	103°35'27"	44°08'27"	103°35'28"
9	44°17'25"	102°39'02"	44°17'22"	102°39'05"	44°17'25"	102°39'02"
10*	44°30'07"	102°44'23"	44°30'09"	102°44'30"	44°30'08"	102°44'18"
11*	44°29'55"	103°17'03"	44°29'49"	103°17'14"	44°29'50"	103°17'04"
12*	44°55'22"	103°45'44"	44°55'23"	103°45'50"	44°55'22"	103°45'50"

*Questionable point

TABLE 21. COMPARATIVE COORDINATE DATA FOR BASE MAP AND DIRS-RECTIFIED LANDSAT CCT'S.

Test Point No.	July CCT-USGS		Sept. CCT-USGS		July - Sept.	
	Lat (Sec)	Long (Sec)	Lat (Sec)	Long (Sec)	Lat (Sec)	Long (Sec)
1	2	2	1	0	1	2
2	1	9	0	10	1	1
3	6	3	4	4	2	1
4	7	18	7	18	0	0
5*	5	19	6	23	1	4
6	3	1	2	3	1	4
7	4	5	1	3	3	2
8	3	6	1	7	2	1
9	3	3	0	0	3	3
10*	2	7	2	5	0	12
11*	6	11	5	1	1	10
12	1	6	0	6	1	0

Avg. |n|

(Sec) 3.5 7.5 2.4 6.6 1.3 3.2

(meters) 107 157 67 161 49 38

(feet) 351 515 220 528 161 125

*Questionable point

determine an explanation for the discrepancies. The first investigative step was the confirmation that the DIRS parameters and K-class training data were the same for each classification run. Next, the effect of classifying over substantially different longitudinal distances was investigated. Involved here was the effect of varying the interpolation grid spacing when determining resample locations in the CCT data. This phenomena occurs because the number of grid lines was held constant for all classification runs. Test results indicated that interpolation grid spacing was not a factor in the classification discrepancies.

The third possible explanation which was investigated concerned the effects of small variations in the initial resample location. Relative displacements of two seconds in the longitudinal direction and one second in the latitudinal direction resulted in substantial classification differences for a small test area. In addition, it was found that K-class was very sensitive to small changes in pixel values. Therefore, the combination of resampling location and K-class sensitivity is offered as explanation for the observed discrepancies. However, much research remains to be done in this area.

MAPCLASS

One of the major benefits of using remote sensing as a natural resource data source is the ability to extract data over large areas. Use of Landsat expands single-frame coverage to the immense areas of almost 3.5 million hectares (8.5 million acres). When the added dimension of temporal coverage is included, the potential amount of resource data might overwhelm conventional data storage/manipulation techniques.

Considerable effort was expended in the evaluation of entering remotely-sensed and other resource information into a computer-based data system. MAPCLASS is a program which allows for the manual coding of change-points rather than coding every cell in a grid system. The

program also has overlay capabilities and can manipulate numerous resource data combinations entered into the data base. Output via plotter allows generation of maps at user-specified scales as opposed to restriction of scale apparent on printing devices.

The data are encoded as a grid of rows and columns and can be referenced to any one of a variety of coordinate systems. Two systems, latitude/longitude and range/township, appeared to be the most practical. Data in a latitude/longitude system are easier to manage; however, few South Dakotans are familiar with latitude/longitude as a ground reference system. South Dakota is subdivided into townships by a range/township ground survey. Because the nomenclature is widely used and understood, the decision was made to evaluate a data-base grid system using range and township lines as ground reference. A 1:250,000 USGS Quadrangle map of the area allowed development of a MAPCLASS grid system which accounted for range correction lines and township lines as adjusted for earth curvature. The basin was then divided into eight sections varying in size from eight to 30 townships each. These eight sections (Figure 42) are essentially "square" (i.e. correction lines are absent in each of the eight sections).

The basic cell size of 16.2 hectares (40 acres) was selected because it is small enough to obtain desired detail but large enough to keep digitizing times reasonable. The 16.2 hectare (40 acre) grids that were used in the digitization process were generated using the CALCOMP plotter and associated software. Data coding involved recording the grid row and column number of change points in the data.

Coded Data

Data entered into the MAPCLASS data base included: surface water, land use, soil associations, slope of land, sub-basin delineation, Black Hills National boundary, country boundaries, and range/township lines.

Initially, a 1:250,000 Landsat surface water interpretation was manually entered into MAPCLASS by determining the grid coordinate,

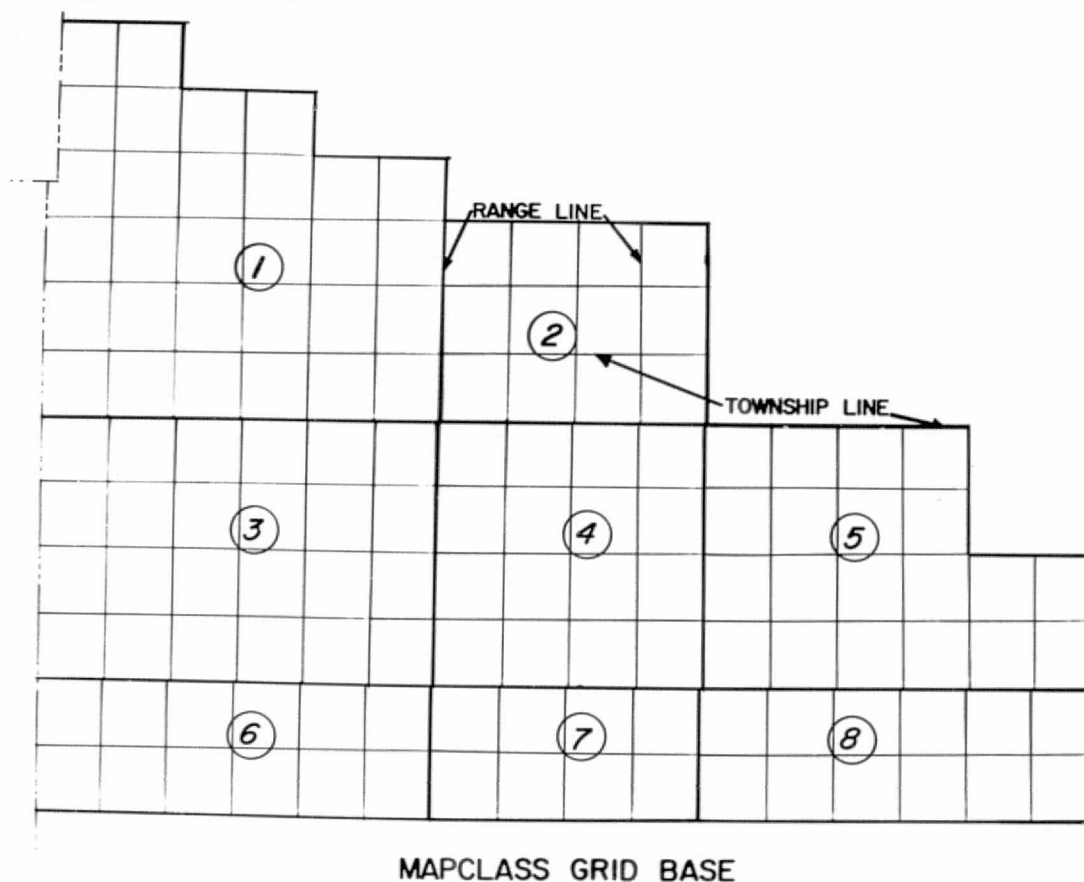


Figure 42. MAPCLASS grid base as developed from inspection of existing USGS maps. Eight "sections" are each square in themselves yet remain tied to the Range and Township ground survey system used in South Dakota.

number, and approximate size of interpreted surface water present in the 16.2 hectare (40 acre) cell. The water was classified into one of six categories: single water bodies of .4-4 hectares (1-10 acres), 4.5-8.1 hectares (11-20 acres), 8.5-16.2 hectares (21-40 acres) per cell, and two, three, or four .4-4.0 hectares (1-10 acre) bodies of water in a single cell. The sizes were approximated by visual comparison of the interpreted water with the basic cell unit. On this initial coding effort, major river/stream systems were also entered into the data base. Included in the MAPCLASS output is a tabulated summary of frequency and total area involved with each classification code. Figure 43 shows digitized Landsat surface water data superimposed on a 1954 USGS map. Discrepancies between maps and Landsat interpretations were addressed and are reported in the surface water section.

Because of the time involved to manually digitize the surface water data (41 man-hours) on this initial use of MAPCLASS, an evaluation of an automated data entry procedure was initiated. The method combined the visual interpretation data with the image digitizing capabilities of RSI's SADE system (see Appendix). A township interpreted for surface water was randomly selected from the 1:250,000 data and was masked off so that only the single township's interpreted surface water was visible. At a digitizing resolution of 256 pixels per 57 mm (2.25 inches), there are 36 pixels per 16.2 hectare (40 acre) grid cell (i.e., each cell would be six pixels wide). Line printer maps of the digitized data resulted in the confirmation that 65 of the 69 interpreted bodies of water within the township had been digitized. It is assumed that the four not digitized were integrated into more than one pixel with the resultant value being above the threshold value. Subsequent automated evaluation of surface water interpretations resulted in the conclusion that 1:250,000 is not an optimum scale for visual Landsat surface water interpretations. For an automated digitizing technique as described above, 1:125,000 interpretations

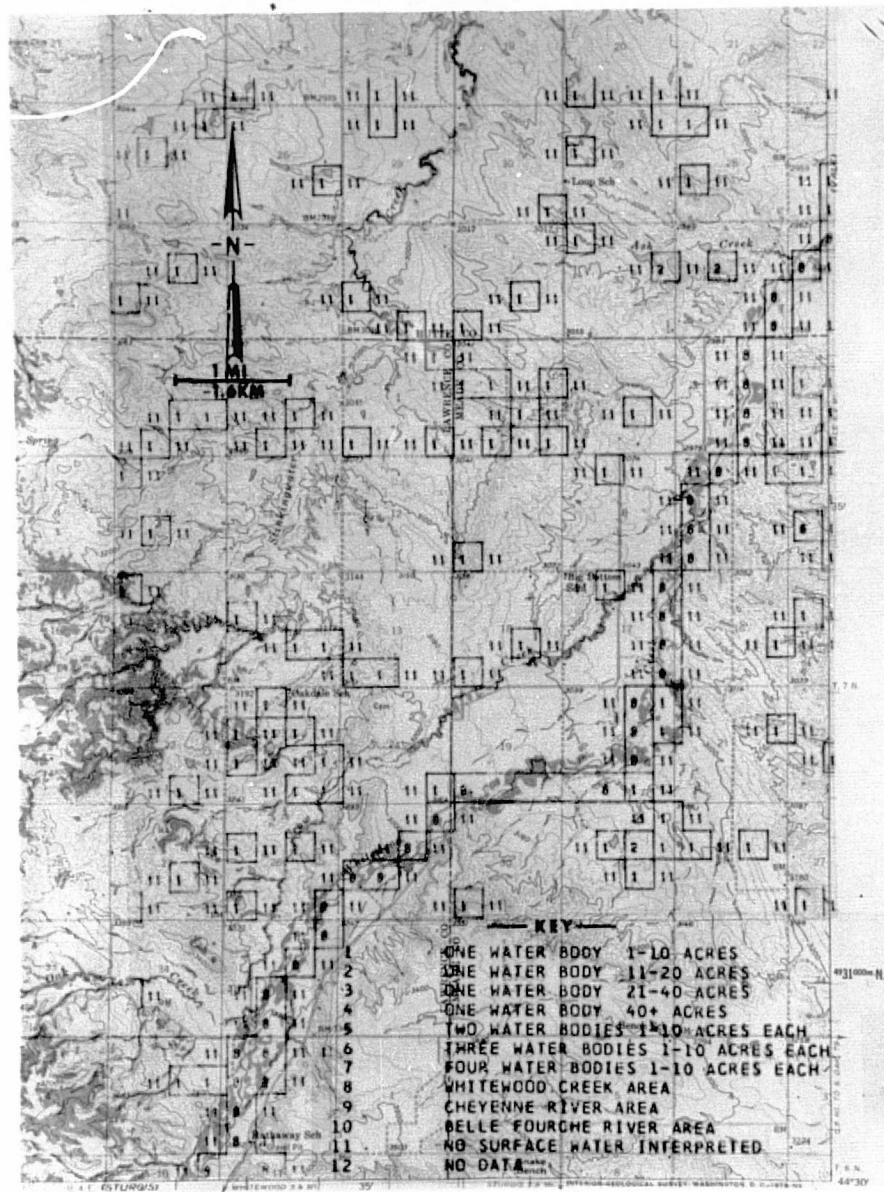


Figure 43. Digitized 12 June 75 Landsat MSS 7 data superimposed on 1954 USGS map.

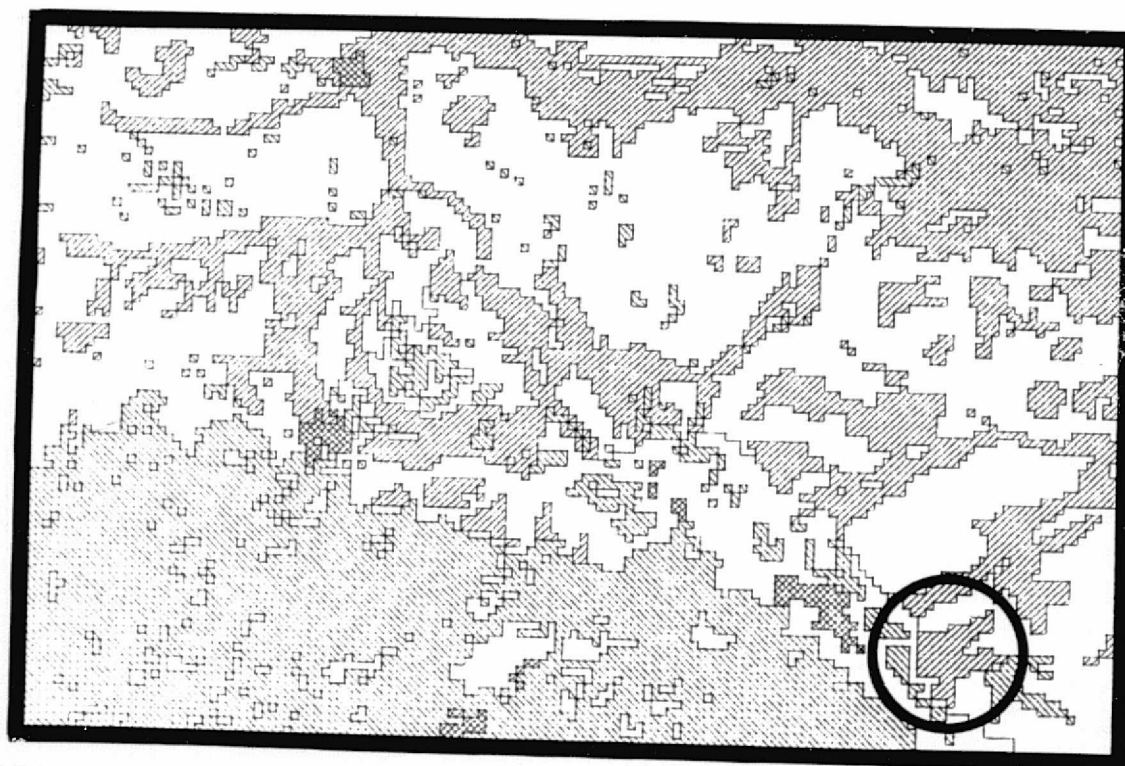
(the preferred interpretation scale) would be more costly. It appears that the automated digitizing has potential but that considerable procedural evaluation and development is required before an operational system is established.

Based on the land use interpretation recommendations of this study, the entire Belle Fourche River Basin was interpreted at 1:125,000 for Level I land use. These land use data were manually coded into the MAPCLASS data base. Other data entered into a basin-wide data base include: sub-basin boundaries, soil association, county boundaries, Black Hills National Forest boundary, and range/township lines. Figure 44 is the Landsat-based Level I land use for Section 3 (see Figure 42). Notice the agricultural area which is circled. This area is enlarged in Figure 45 and demonstrates MAPCLASS overlay capability, in this case agricultural land and soil association. The outlined area of Figure 45 is Landsat-interpreted agricultural land and the boundaries within the agricultural land are soil association boundaries which were digitized from existing soil association maps and combined with the land use data. MAPCLASS also allows user-designated combinations within overlays. For example, if the Grummit-Pierre and Kyle-Pierre soils were similar in drainage characteristics, they could be combined into a new interpretation classification. Any overlay combination is possible and, using a plotter output, any scale map is available.

Using the SADE system in conjunction with MAPCLASS output, data can be displayed and electronically color-coded as shown for the Lawrence County land use data in Figure 46. While the plotter output of lines and numerical descriptors may be adequate for most work, the added dimension of color plus the ability to selectively display and electronically planimeter individual color categories would be of benefit to certain studies, reports, and presentations.

The interpreted agricultural land use (see land use section) as outputted by MAPCLASS for the entire basin is seen in Figure 47.

LANDUSE SECTION 3



KEY:



AGRICULTURE



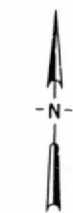
RANGE



FOREST



URBAN



5KM

Figure 44. Level I land use for Section Number 3 (see Figure 42) as interpreted from Landsat color composite data and stored in MAPCLASS. The circled agricultural area is also seen in Figure 45 as an example of the MAPCLASS overlay capability.

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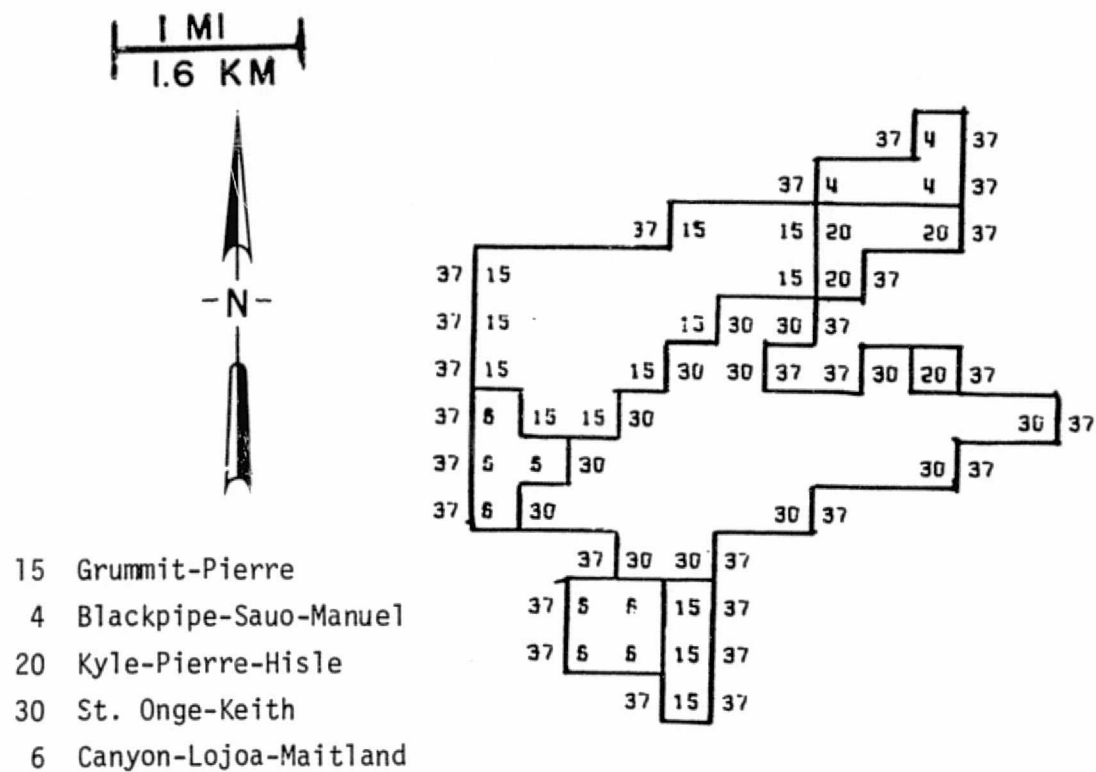


Figure 45. The agricultural area circled in Figure 44 as overlaid with MAPCLASS encoded soil association data.

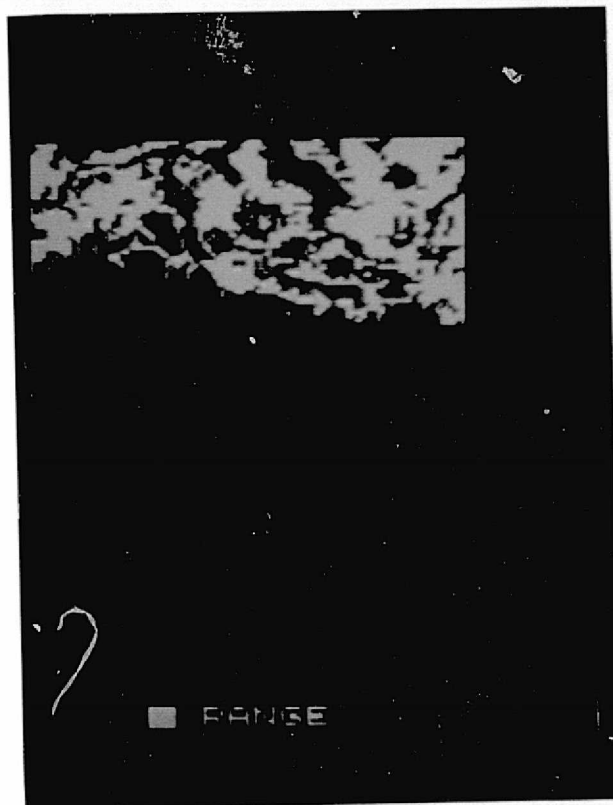


Figure 46. Color print of the SADE monitor output of MAPCLASS encoded land use data for Lawrence County.

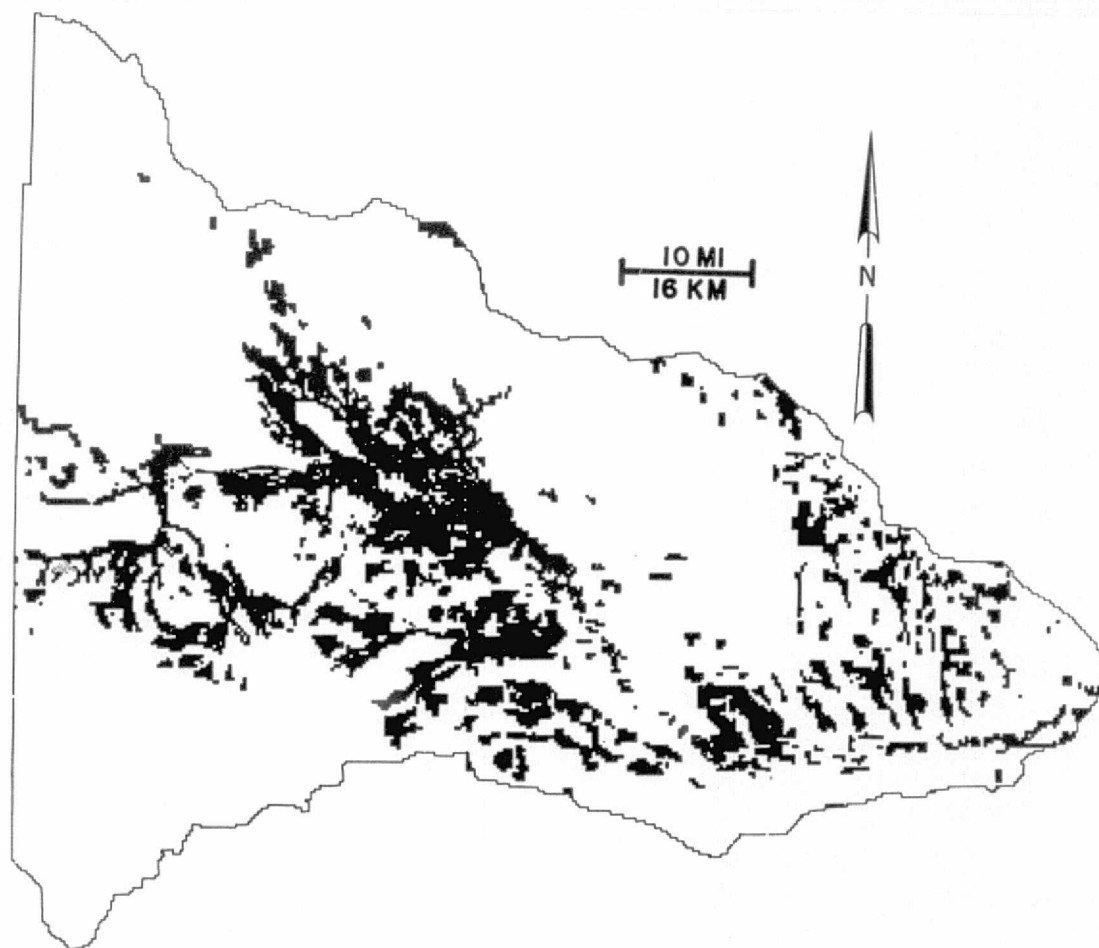


Figure 47. Agricultural land use in the Belle Fourche Watershed as interpreted from Landsat and coded and plotted via MAPCLASS.

A total of 145,230 hectares (363,080 acres) of ag land (17.4% of the basin) has been interpreted as being under cultivation. Forested areas (interpreted from 1:125,000 winter Landsat imagery) are depicted in Figure 48. A total of 99,375 hectares (248,440 acres) of forested land fall within the basin. It is interesting to note that within general boundaries of the Black Hills, some 8,110 hectares (20,280 acres) are non-forested (meadows, etc.). Rangeland comprises the vast majority of land use 579,262 hectares (1,448,156 acres) of this basin with the remaining portion 2,016 hectares (5,040 acres) made up of urban area. Once coded into MAPCLASS, as these data are, maps and overlays at any scale are available to the user. Examples of other coded data are seen in Figure 49. With the exception of sub-basin boundaries, all other data were obtained from existing maps of the area. A basin boundary map was produced using techniques described in the drainage network section. Much of the data excepting land use coded into MAPCLASS would not markedly change with time. In such cases, there would be only initial digitizing costs. Once placed into the data base, the only costs incurred would be those to run the program. Other more variable data such as land use can be easily updated.

Data Timeliness

One of the distinct advantages of Landsat data, in comparison to more conventional data sources, is its timeliness. For many studies, like aspen and general land use mapping, data delivery within six months to one year of collection would be considered "new" enough. However, for the more dynamic hydrologic basin conditions such as surface water fluctuations, the timing becomes critical and should be reduced to less than a week from date of imaging to date of delivery to users. A record was kept on the EROS Data Center standing Landsat orders. For 35 delivered orders, the average delivery data was eight weeks from the date of data collection. For current water resources monitoring in an operational situation, this would be an unacceptable turnaround time.

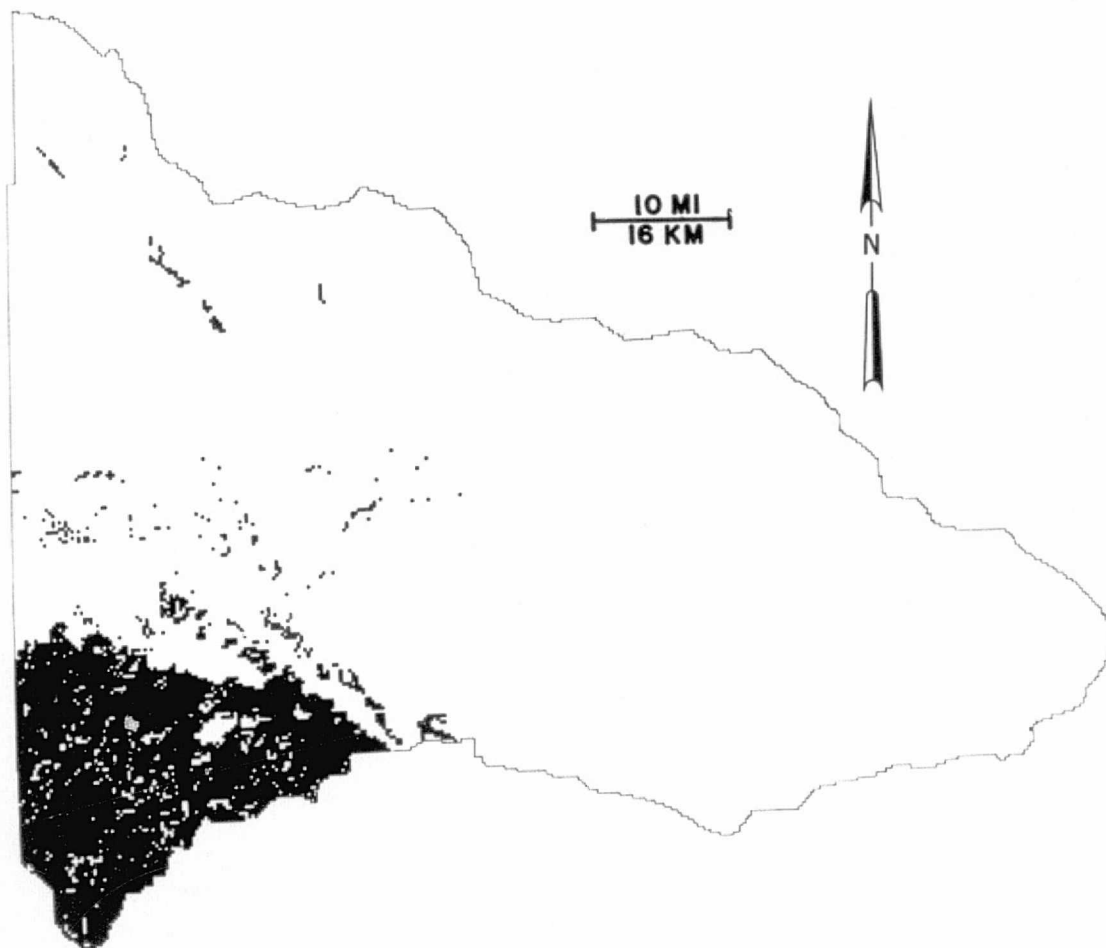


Figure 48. Landsat-interpreted winter imagery interpreted at 1:125,000 and coded into MAPCLASS allowed this mapped record of 99,375 hectares (248,440 acres) of forested lands within the Belle Fourche River Basin.

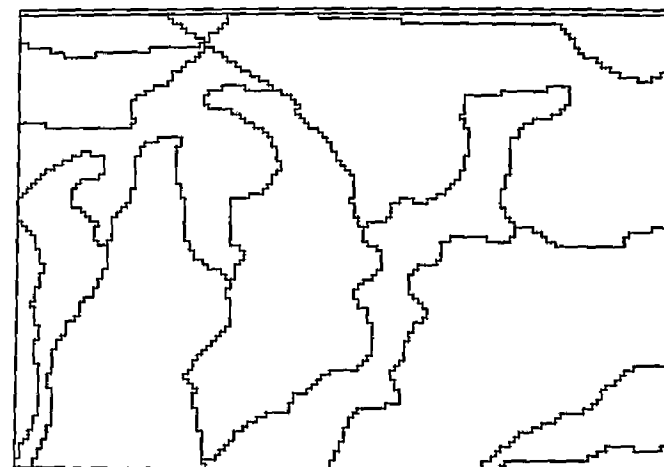
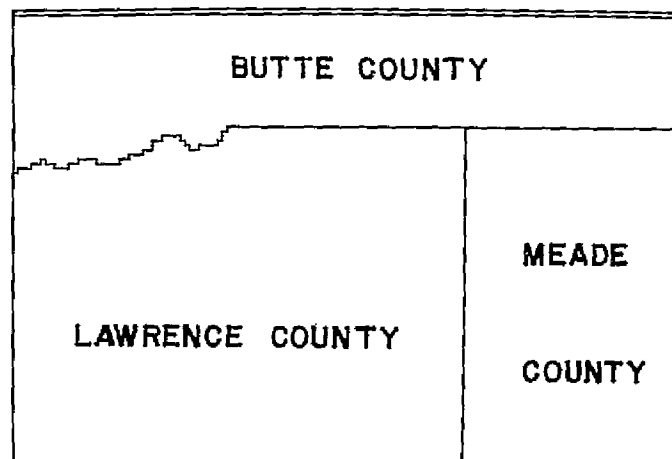
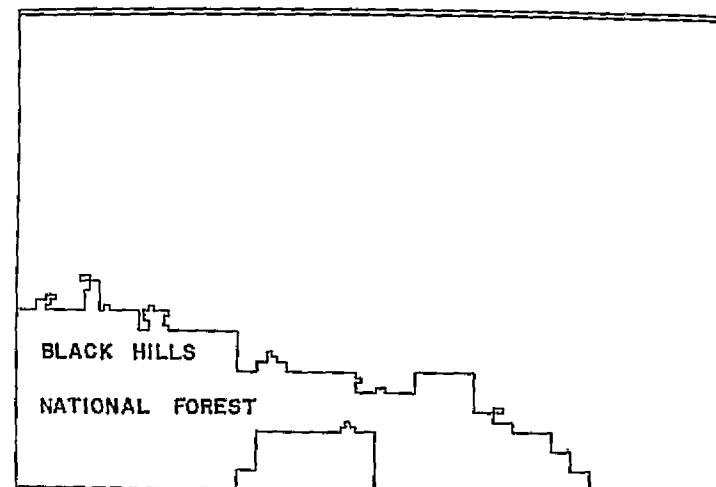
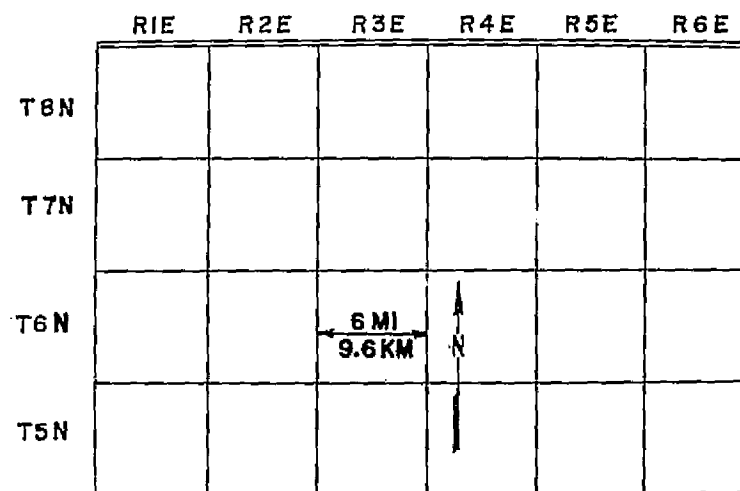


Figure 49. Various data can be entered into the MAPCLASS data base. Range and Township lines (a), Forest Boundaries (b), and County Boundaries (c), are data transferred from other existing maps. Land use (Figure 44) and drainage sub-basins (d) are data interpreted using remote sensing techniques.

High altitude imagery was delivered three months after data collection, again too late for operational water monitoring situations. Such a turnaround time is also unacceptable for providing usable data for mountain pine beetle infestation control work which requires delivery within one month of a September collection date. It is remembered that contractual agreements with commercial firms would allow for collection of aerial photography as specified by the user.

V. COST EFFECTIVENESS

Introduction

In many decision-making situations, very little attempt is made to consider the various possible alternatives and to judge the differences between them. As a result, numerous decisions are based primarily on guesswork and/or intuition. Many unwise investments will be made and many wise ones will fail to be made if important decisions regarding proposed expenditures are entertained with little attempt to clearly define the possible alternatives. Such a definition requires generation of a basis that makes the available choices commensurable. A monetary comparison, it seems, is the only method which provides units that make commensurable alternatives out of physically different alternatives. The attempt to answer the question, "Which method do we select?" involves reducing the variables to monetary terms. The cost-effective choice between alternative methods must then be given weight for those differences that have been impractical to reduce to monetary terms (23).

A cost-effective analysis for land use mapping, surface water inventories, aspen delineation, drainage map preparation, DIRS, and MAPCLASS are presented in this section. These applications were selected because of their immediate potential applicability and the operational nature of the data handling procedures.

To conduct this cost study, some basic assumptions were made. High and low altitude aircraft flight altitudes were assumed as 18,300 meters (60,000 feet) and 3,050 meters (10,000 feet), respectively. Flight line side overlap was taken as 30 percent and stereo overlap as 60 percent. Cost estimates for data collection, labor, equipment, interpretation, and other variables were estimated from data and records gathered throughout this effort. Landsat data costs were obtained from the August, 1975 EROS price list. Another assumption basic to this analysis is that of single use of data. Proper coordination, timing, and planning might permit a user to contract for a flight or purchase Landsat data and use the acquired data for more than one particular survey. For example, land use and drainage information might be gathered from the same data source. Detailed land use/drainage studies might be interfaced with surface water inventories for a certain area. The overall effect would be one of cost reduction on a "per application" basis. This multiple-use effect was not evaluated in the cost analysis.

Land Use

There are a variety of data sources available for land use studies in South Dakota. These sources include: high altitude aerial photography, low altitude photography, Landsat MSS imagery, digital Landsat CCT analysis, ground surveys, and conventional data sources.

Initial land use mapping costs are incurred in data collection. Such costs are summarized for an area similar to the Belle Fourche River Basin in Table 22. Aircraft data acquisition includes delivery of a color infrared film product. Two Landsat standard false-color composite transparencies are listed as are two Landsat MSS 1600 bpi scenes (with MSS 4,5,6,7 included in each scene). The ground survey estimate is subdivided in Table 23. The present method of land use data collection is of no cost as data are available (in tabular form) in books prepared by other government agencies.

TABLE 22. LEVEL I LAND USE DATA COLLECTION COSTS.

Source	Flight Cost \$/line kilometer (\$/line mile)	Line Kilometers (miles)	Total Acquisition Costs (\$)
High Altitude Aircraft	15.5 (25)	724 (450)	11,250
Low Altitude Aircraft	6.2 (10)	2413 (1500)	15,000
Landsat Color Composite	--	--	124
Landsat CCT (Two Scenes)	--	--	400
Ground Survey	--	--	17,900
Present Method	--	--	No Charge

TABLE 23. GROUND-LEVEL LEVEL I LAND USE SURVEY.

No. Townships surveyed:	100
No. Townships per day:	1
Per diem (@ \$30 per day)	\$ 3,000
Support (@ \$112 per day)	\$11,200
Travel (to and from site) (one time)	\$ 100
Car rental (\$6/day; \$.05/km, \$.08/mi; 400km/day, 250mi/day)	\$ 2,600
Gasoline (6km/l, 15mi/gal; 400km/day, 250mi/day; \$.15/l, \$.60/gal)	<u>\$ 1,000</u>
TOTAL	\$17,900

With raw data collected, the next step is land use data extraction. Using film data, there are essentially two sources for visual interpretation: prints or transparencies. Included in a cost estimate for interpreting transparencies is equipment costs. A basic analysis system for aircraft film interpretation would require a light table. For a basic Landsat transparency interpretation, magnification as well as illumination is required. Interpretation time is based on the estimated number of frames and interpretation of data as conducted during the course of this study. Total labor cost was estimated as \$112 a day. Without the purchase of equipment, these figures indicate that not only is Landsat data much less expensive for a user to obtain (Table 22) but also it is the least expensive from which to extract visually interpreted data for applications relating to Level I land use. It should be remembered that equipment outlays are required only once and the equipment may already be available. For this reason, costs including and excluding basic interpretation equipment are listed in Table 24.

Interpretation of color prints is the other visual interpretation alternative. Prints can be interpreted either in a mosaicked or unmosaicked format. The decision to mosaic might depend upon individual job requirements and labor costs. The estimates using print data are found in Table 25. Interpretation and mosaic time requirements were estimated using experience gained through this effort. Labor costs are \$112 per day. The relationship (i.e., more economical method) between mosaicked or unmosaicked data formats might be a relative one depending upon personnel costs and abilities. For that reason, it is suggested that there can be no specific conclusion stating that one particular method of interpretation would always be the least expensive.

Computer analysis costs for Landsat CCT land use interpretations are listed in Table 26. This cost summary is based on data extraction for an area the size of the Belle Fourche River Basin, and the

TABLE 24. VISUAL LEVEL I LANDUSE INTERPRETATION USING FILM DATA.

Source	Equipment Cost (\$)	No. Frames	Interpretation Time (days)	Interpretation Cost (\$)	COST	
					With Equip (\$)	Without Equip (\$)
High Altitude Aircraft	1000	75	10	1120	2120	1120
Low Altitude Aircraft	1000	1800	45	5040	6040	5040
LANDSAT Color Composite	3000	2	2	224	3224	224
LANDSAT CCT	--	--	--	--	--	--
Ground Survey	--	--	--	--	--	--
Present Method	--	--	--	--	--	--

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classification of three Level II agricultural classes, water and rangeland. It should be mentioned that, generally, SPB attempts to extract as many categories as possible from the data. Consequently, cost figures are not available for Level I categories.

TABLE 26. LANDSAT CCT ANALYSIS COSTS FOR THREE LEVEL II AND TWO LEVEL I LAND USE CATEGORIES.

CPU (5.5 hours at \$300/hour)	\$ 1650
Analyst Time (10 days at \$112/day)	<u>1120</u>
Total Cost	\$ 2770
Cost Per Township (100 Townships)	<u>\$27.70</u>

All land use data sources are summarized in Table 27. On a cost per township basis, the figures are listed in Table 28.

Surface Water

Surface water cost summaries were conducted similarly to those reviewed for land use. Data collection costs are as listed in Table 29. Only MSS 7 imagery is required as the visual Landsat data source. The ASCS photo-index sheet (the present DNRD data source) and the larger ASCS individual photographs are also included in this evaluation. The Landsat and ASCS data appear considerably less costly as compared to other data sources.

Visual interpretation of transparency film data is reviewed in Table 30. The same comments pertaining to equipment purchases in the land use cost estimates are applicable for surface water. In a similar manner, visual surface water interpretation costs using prints are listed in Table 31. For this analysis, interpreting unmosaicked versus mosaicked appears as more cost-effective in all but Landsat MSS 7. The decision between use of transparencies and mosaicked or unmosaicked prints would depend upon job requirements as well as cost considerations.

TABLE 27. COST SUMMARIES FOR LEVEL I LANDUSE INFORMATION USING OPERATIONAL DATA SOURCES.

Source	Data Acquisition	DATA INTERPRETATION					Other (\$)
		TRANSPARENCY		PRINT			
		With Equip (\$)	Without Equip (\$)	With Mosaic (\$)	Without Mosaic (\$)		
High Altitude Air	11,250	2120	1120	1253	1589	--	
Low Altitude Air	15,000	6040	5040	20,322	16,290	--	
LANDSAT Color	124	3224	224	318	520	--	
LANDSAT CCT	400	--	--	--	--		2270*
Ground Survey	17,900	--	--	--	--	--	
Present Method	--	--	--	--	--		56**

* Cost includes categorization of three Level II agricultural classes, water and rangeland.

** Cost of estimated .5 manday to extract landuse data from existing tabular data.

TABLE 28. PER TOWNSHIP COSTS (including acquisition costs) FOR LAND USE MAPPING.

Source	TRANSPARENCY		PRINT		Other (\$)
	With Equip (\$)	Without Equip (\$)	With Mosaic (\$)	Without Mosaic (\$)	
High Altitude Aircraft	134	124	125	128	--
Low Altitude Aircraft	210	200	353	313	--
Landsat Color	33	3	4	6	--
Landsat CCT*	--	--	--	--	27*
Ground Survey	--	--	--	--	179
Present Method	--	--	--	--	<1

*Cost includes categorization of three Level II agricultural classes, water, and rangeland.

TABLE 29. SURFACE WATER DATA COLLECTION COSTS FOR AN AREA
SIMILAR TO THE BELLE FOURCHE RIVER BASIN.

Source	Flight Cost \$/line kilometer (\$/line mile)	Line Kilometers (miles)	Acquisition Cost (\$)
High Altitude Aircraft	15.5 (25)	724 (450)	11,250
Low Altitude Aircraft	6.2 (10)	2413 (1500)	15,000
Landsat MSS 7	--	--	10
Landsat CCT	--	--	400
Ground Survey	--	--	17,900
ASCS (photo index)	--	--	100
ASCS (1:7920)	--	--	5,850

TABLE 30. INTERPRETATION COSTS USING TRANSPARENCY DATA FOR VISUAL SURFACE WATER MAPPING.

Source	Equipment (\$)	No. Frames	Interpretation Time (days)	Interpretation Cost (\$)	COST	
					With Equip (\$)	Without Equip (\$)
High Altitude Aircraft	1000	75	5	560	1560	560
Low Altitude Aircraft	1000	1800	37	4144	5144	4144
LANDSAT MSS7	3000	2	2	224	3224	224
LANDSAT CCT	--	--	--	--	--	--
Ground Survey	--	--	--	--	--	--
ASCS (Photo Index)	--	--	--	--	--	--
ASCS (1:7920)	--	--	--	--	--	--

TABLE 31. COST SUMMARY FOR VISUALLY INTERPRETING PRINTS FOR SURFACE WATER.

Source	Cost Prints (\$)	No. Prints	Mosaic Labor (Days)	Mosaic Labor (\$)	Mosaic Interp (Days)	Mosaic Interp (\$)	Print Interp (Days)	Print Interp (\$)	COST	
									With Mosaic	Without Mosaic
High Altitude Aircraft	150	75	3	336	2	224	5	560	710	710
Low Altitude Aircraft	3600	1800	75	8400	3	336	37	4144	12,336	7744
LANDSAT MSS7	38	4	.2	22	1	112	2	224	172	262
LANDSAT CCT	--	--	--	--	--	--	--	--	--	--
Ground Survey	--	--	--	--	--	--	--	--	--	--
ASCS (Photo Index)	100	20	2	224	2	224	3	336	548	436
ASCS (1:7920)	5850	900	38	4256	3	336	19	2128	10,442	7978

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Computer compatible tapes are another alternative for agencies requiring surface water data. The costs incurred in the use of CCT's are summarized in Table 32.

TABLE 32. LANDSAT CCT DATA COSTS FOR SURFACE WATER ANALYSIS.

CPU (14.5 minutes @ \$5/minute)	\$72.50
Analyst Time (30 minutes @ \$14/hour)	<u>7.00</u>
Total Cost	\$79.50
Cost per Township	\$ 0.80

All surface water cost data are summarized in Table 33. The costs are for an inventory of water over an area the size of the Belle Fourche River basin at a scale of 1:125,000. In the case of Landsat CCT's, the scale is approximately 1:24,000. On a total cost-per-township basis, a surface water inventory can be conducted for the costs listed in Table 34.

When considering data acquisition and interpretation costs, an aerial photograph inventory appears to be greater than a Landsat-based survey by a factor of 100. Low altitude photography (approximately twice as costly as high altitude data) approaches the cost of an actual ground survey. The present data source ASCS photo index) is also the second-most economical (after Landsat), with the individual ASCS prints falling in the general \$100 per township range of high altitude photography. A digital analysis of CCT data is more expensive than a visual Landsat interpretation but is within the present expenditures for water inventory methods. Data acquisition costs account for a major percentage of the costs listed in Table 34 (see Table 33). It must be recognized that, for certain applications, use of historic data is acceptable and would result in substantially reduced costs for aerial photography.

TABLE 33. SURFACE WATER INVENTORY COSTS FOR AN AREA SIMILAR TO THE BELLE FOURCHE RIVER BASIN.

Source	Data Acquisition (\$)	INTERPRETATION				Computer (\$)
		TRANSPARENCY		PRINT		
		With Equip (\$)	Without Equip (\$)	With Mosaic (\$)	Without Mosaic (\$)	
High Altitude Aircraft	11,250	1560	560	710	710	--
Low Altitude Aircraft	15,000	5144	4144	12,336	7744	--
Landsat MSS 7	10	3224	224	172	262	---
Landsat CCT	400	--	--	--	--	80
Ground Survey	17,900	--	--	--	--	--
ASCS (Photo Index)	*	--	--	548	436	--
ASCS (1:7920)	*	--	--	10,442	7978	--

*Included as print cost

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TABLE 34. PER TOWNSHIP COSTS (including acquisition costs) FOR
SURFACE WATER MAPPING.

Source	TRANSPARENCY		PRINT		Other (\$)
	With Equip (\$)	Without Equip (\$)	With Mosaic (\$)	Without Mosaic (\$)	
High Altitude Aircraft	128	118	120	120	--
Low Altitude Aircraft	201	191	273	227	--
Landsat MSS 7	32	2	2	3	--
Landsat CCT	--	--	--	--	5
Ground Survey	--	--	--	--	179
ASCS (Photo Index)	--	--	5	4	--
ASCS (1:7920)	--	--	104	80	--

Analysis of aerial photography costs \$100-200 per township (including data collection) for surface water analyses, whereas Landsat data costs are much less. A considerable amount of aerial data costs are due to data collection. While increased detail is available with aerial photography compared to Landsat, the value of this added detail must be weighed. For each use the importance of the data should be determined by expense, repetitive coverage, timeliness, and detail. For state-wide inventory purposes, detail to .2 ha (.5 acres) is required by DNRD. This precludes use of Landsat as an only source. However, because of the costs of aircraft data collection, these sources are also unacceptable. Continued use of inexpensive ASCS photo-index sheets for base inventory and use of Landsat imagery for monitoring and entering obvious changes is expected.

Aspen Delineation

Aspen mapping costs were estimated for the entire South Dakota portion of the Black Hills. Data sources included in the cost study are those listed in Table 35. The data sources listed were included based on potential operational application as indicated during this study. A ground survey was not included in the survey as it was considered an impractical approach in the mountainous Black Hills.

TABLE 35. ASPEN DATA COLLECTION FOR THE BLACK HILLS.

Source	Flight Cost \$/Line Kilometers (\$/Line Mile)	Line Kilometers (Miles)	Total Acquisition (\$)
High Altitude Aircraft	15.5 (25)	483 (300)	7,500
Low Altitude Aircraft	6.2 (10)	1600 (1000)	10,000
Landsat CCT	--	--	400
U.S. Forest Service	--	--	No Cost

As with surface water and land use mapping, the two data sources for visually interpreting aspen are transparencies and prints. Using transparency data, aspen interpretations are summarized in Table 36. Low altitude film data indicates interpretation costs approaching twice those incurred using high altitude aircraft imagery.

TABLE 36. VISUAL ASPEN INTERPRETATION USING TRANSPARENCY DATA.

Source	Equip (\$)	No. Frames	Interp. Time (Days)	Interp. Cost (\$)	COST	
					With Equip (\$)	Without Equip (\$)
High Altitude Aircraft	1000	60	60	6720	7720	6720
Low Altitude Aircraft	1000	1200	100	11,200	12,200	11,200
Landsat CCT	--	--	--	--	--	--
U.S. Forest Service	--	--	--	--	--	--

Color prints can be interpreted at costs summarized in Table 37. A substantial advantage of mosaic interpretation is indicated for high altitude data. The cost required to mosaic 60 prints is less than the cost incurred in attempting an individual print analysis. That is, 23 days are required to mosaic and interpret the data whereas 60 days are required to interpret and register each print individually. High altitude analysis is less costly than low altitude aspen analysis.

Visual Landsat aspen interpretation proved unacceptable for GF&P requirements. Digital analysis of CCT data proved more acceptable. For an area the size of the Black Hills, such a computerized analysis could be conducted with costs as summarized in Table 38. Two CCT's are required to provide coverage of the Black Hills. Costs relating to rectification, training the classifier, data extraction, actual data processing, plotting, and labor are included in this estimate. The major cost (labor) might be reduced as experience is gained and methods are improved.

[illegible]

TABLE 38. DIGITAL ANALYSIS OF LANDSAT CCT DATA FOR ASPEN MAPPING OF THE BLACK HILLS.

Purchase CCT's	\$ 400
DIRS (two scenes)	1600
Train Classifier	150
Extract Data	434
Run Classifier	680
Plot	56
Labor	<u>1400</u>
Total Cost	\$4720
Cost Per Township ($\div 75$)	\$ 63

Combining the data of Tables 36, 37, and 38, and adjusting for a cost-per-township figure (75 townships), Table 39 is generated as a summary of aspen mapping costs. Again, low altitude data is twice as expensive as high altitude data and Landsat CCT products are approximately one-third the cost of the high altitude data. For detailed analysis, the use of historical aircraft imagery could be considered, but the inventory would not then be timely.

Drainage Network, DIRS, MAPCLASS

Costs incurred in the preparation of a drainage map will be extremely variable, depending upon the area surveyed, amount of data available on existing maps, and the type of imagery available for the area. The developed procedure uses as its base Landsat data. For all unmapped regions of South Dakota, Landsat data are known to exist. For these reasons, costs are estimated based solely on the use of Landsat as a data source. The costs for an area the size of the Belle Fourche River Basin are summarized in Table 40 and the cost-per-township would then be approximately \$8.

TABLE 39. COST IN DOLLARS PER TOWNSHIP FOR A VARIETY OF ASPEN MAPPING ALTERNATIVES.

Source	TRANSPARENCY		PRINT		Other (\$)
	With Equip (\$)	Without Equip (\$)	With Mosaic (\$)	Without Mosaic (\$)	
High Altitude Aircraft	203	190	145	206	--
Low Altitude Aircraft	296	283	368	383	--
Landsat CCT	--	--	--	--	55
U.S. Forest Service	--	--	--	--	No Cost

TABLE 40. ESTIMATED COSTS TO DEVELOP A DRAINAGE NETWORK FOR AN AREA SIMILAR TO THE BELLE FOURCHE RIVER BASIN USING LANDSAT MSS IMAGERY.

Black and White Prints	\$ 20
Color Composite Prints	40
Interpretation	560
Drafting	<u>224</u>
	\$844

The DIRS package requires approximately \$300 in computer time and \$400 technician time per rectified scene. This costing figure does not reflect plotting.

Records were kept during the evaluation of MAPCLASS and they have been converted to cost-per-township in Table 41. The costs listed in Table 41 include coding costs, cards, keypunching, and computer time. An extensive MAPCLASS data base development program should probably be implemented via budgeted funds, as the costs for entering data on a state-wide basis would be considerable. It is felt that in such an application, the true value and capabilities of the program would be realized.

TABLE 41. COST OF MAPCLASS AS A DATA HANDLING MEDIUM.

Data	Cost/Township (\$)
Soil Association	4.70
Slope of Land	10.60
Level I Land Use	5.10
Sub-Basin Boundaries	1.40
National Forest Boundaries	.40
Counties	.70
Range/Township Lines	.70
Surface Water	2.20

VI. SUMMARY

Based on the results of the applications and cost-effectiveness studies as conducted in this effort, numerous operational remote sensing methods have been identified by South Dakota state agencies. A brief review of operational and potential applications follows:

Land Use

Successful applications of remote sensing for land use mapping were demonstrated. Agencies specified a common need for basic Level I land use information and more restricted requirements for greater detailed mapping. While extensive ground surveys would likely produce the most detailed data, the costs are excessive and preclude use except on a highly confined basis. Low altitude data, visually interpreted, is also expensive (approximately \$300 per township, including data collection). However, such data is adequate for Level II analysis of areas similar to the "strip" where monitoring is required over a relatively small area.

Data greater than Level I are available from the more expensive aircraft data sources; but unless such detail is required, these sources should not be used for the basic Level I mapping effort. It is important from a cost standpoint to match data requirements with data sources.

An optimum Level I land use source would appear to be visual interpretation of 1:125,000 color Landsat prints. Such interpretations could produce timely Level I maps of accuracies in excess of 80 percent for agricultural lands identification. Such accuracies are acceptable to the various agencies for their respective requirements.

For hydrological studies, land use information is desired on a river basin basis. Present methodology precludes development of timely land use data to include location as well as areal extent based on the basin's geographical boundaries rather than county borders. Visual Landsat interpretations allow for the preferred method of data

presentation. DNRD will employ available Landsat data in land use studies conducted on subsequent watershed analyses.

The costs of the present method of obtaining land use information from printed tabular data are the most attractive of those sources analyzed. However, participating agencies agree that the cost increase in advancing from the present procedure to a satellite-based source is justified in terms of expanded data content.

Surface Water

Water monitoring requirements consist of two main interests: complete base inventories and monitoring of these inventories. Based on the results of this study and DNRD requirements; it is concluded that satellite resolution capable of detecting .2 hectare (.5 acre) water bodies is the minimum acceptable for inventory requirements.

Landsat data do not allow for accurate inventory of less than .45 hectare (1.1 acre) water bodies. For this reason, Landsat is not presently considered a viable base inventory tool. Aerial data in the form of ASCS photo-index sheets, the present data source, remains the most cost-effective source for DNRD inventory purposes.

There is a value in present Landsat data for spot-correcting out-dated maps and the older photo-index sheets. A prime asset of present Landsat data in surface water monitoring is its repetitive 9-day cycle over the state. In Western South Dakota, surface areas of stockdams and small reservoir systems can be monitored to provide DNRD and GF&P with a timely approximation of surface water conditions on the range lands. To be of maximum utility, such data should be made available to state agencies on a priority basis (no less than 48 hours after orbit).

Aspen Delineation

Aspen mapping is possible using both aircraft and satellite imagery. Advantages exist for all data sources and application of a particular source depends on agency requirements and fund availability.

High altitude color infrared is preferred for visual analysis. The timing of data collection to coincide with advantageous ground

conditions (i.e., before aspen leaves turn brown but after grass has dried) assists in interpretation. It is important to collect data before the leaves turn color or confusion with the dried grass will occur. Visual interpretation of such imagery results in a certain amount of inconsistencies related to the human aspect of visual interpretation.

These inconsistencies can be reduced through digital analysis of reflectance values as recorded by Landsat CCT's. Combined use of DIRS, K-class, and Landsat CCT's demonstrated the ability to produce aspen maps (at costs less than the aircraft sources) of greater detail and timeliness than is available using U.S. Forest Service maps (when they exist for an area).

Game, Fish and Parks concluded that the results were of significant importance to their mapping efforts and have subsequently participated in a resultant NASA-funded project which will result in an aspen map of the entire Black Hills, using both Landsat and high altitude aircraft color infrared data.

Drainage Delineation

The importance of an accurate drainage map should not be overlooked. A river basin drainage network can provide information on stream flow characteristics and basin water yield. A procedure was developed whereby the highway map drainage information, which for many areas of the state is the only source of drainage data, can be improved upon via visual temporal analyses of Landsat imagery. The procedure was subsequently employed by RSI in an operational application. A Western South Dakota planning district required drainage information for EPA 208 planning. The developed procedures were used for preparation of a seven-county drainage network.

Floodplain Delineation

Floodplain delineation is important for hydrologic studies, planning and zoning, as well as for promoting public safety. In the past, procedures have centered on the use of contour line analysis of 1:24,000

USGS Quadrangle sheets. It was determined by SPB that a combined use of high altitude aerial photography and USGS maps provides the optimum map of flood-prone areas. Where practicable, the procedure will be incorporated into floodplain mapping.

Potential Applications

A number of studies resulted in applications which could not be considered as an operational nature for use by South Dakota agencies at the present time. Included in this group are: crop identification, irrigation delineation, water quality monitoring, and canal leakage detection. The potential for these applications was addressed and further study is recommended to allow development of methodology which will not only demonstrate technical feasibility of such applications, but also will include a cost-effective review. Such facts will allow potential user agencies to similarly evaluate their data requirements with recommended and present methods of data collection and permit them to arrive at a balance of data required and data supplied at the most reasonable cost.

Data Handling

Increased environmental awareness is directly proportional to increased resource-related data handling. Two data handling applications were evaluated in this study: Digital Image Rectification System (DIRS), a NASA-developed Landsat CCT rectification analysis package, and MAPCLASS, an RSI heirarchical data base system. For \$800 per scene, DIRS allows a user analyst to tie each Landsat pixel to a land-based ground coordinate system, rectify the image data, and allow extraction of user-specified "windows" from the image. This study indicated DIRS capable of rectifying data to within two Landsat pixels of actual ground location and providing temporal registration to within a single pixel. DIRS was incorporated into preliminary aspen mapping efforts using Landsat CCT's. It plays an important part in future similar applications.

MAPCLASS data handling techniques were evaluated on a variety of applications varying from historical data transferred from base maps to up-dated remotely-sensed land use information. The interactions and flexibility of data processing allowed by MAPCLASS and similar systems is attractive to resource management specialists in state agencies. Costs of such a program vary considerably with labor costs and the type (i.e., complexity) of data entered into the data base.

VII. CONCLUSION

This study has demonstrated that remote sensing technology is presently capable of being applied to operational resource management problems in South Dakota. Of primary interest is the fact that a majority of the operational applications can be accomplished by present state agency personnel previously untrained in remote sensing or photointerpretation. This evaluation of the current "state-of-the-art" reveals numerous applications of potential value to South Dakota.

Remote sensing is a comparatively new technology and it is changing and progressing at a rapid rate. Such advancements result in an increasing list of diverse operational applications. Those applications not yet considered operational in South Dakota were identified as requiring further study.

In some cases, use of even the least expensive remote sensing data sources (usually Landsat) requires an increase in expenditures over present methods employed by state agencies. Each agency which foresees an actual or potential application for this new resource data source must decide whether the value added by the change in technological applications is worth the cost and effort. A commitment to such a change in data sources may not seem significant, but it represents the initial step in the development of resource management abilities commensurate with resource management potential. The first step is undoubtedly the most difficult and it is definitely the most important. It is the opinion of the personnel working on this project

that the results and training of this activity have been of great assistance to South Dakota agencies in applying remote sensing technology.

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APPENDIX

The Remote Sensing Institute is a research division of South Dakota State University and thereby has access to the full facilities of the University. The Institute is located on the campus in Harding Hall where approximately 43,034 square meters (4,000 square feet) has been allocated to offices and laboratories. The Institute also occupies a 32,275 square meter (3,000 square foot) aircraft hangar and laboratory building which is located off campus at the Brookings, South Dakota Municipal Airport.

The Institute has a large inventory of equipment for use in research activities. A complete photographic laboratory provides color and black and white capabilities. Specialized remote sensing data collection and data analysis equipment including the Signal Analysis and Dissemination Equipment (SADE) system exist within the Institute.

Aircraft Data Collection Equipment

1. One Beechcraft RC45J Aircraft
 - a. An optical-mechanical view finder assists the navigator in observing the coverage of the aerial cameras on the terrain below the aircraft or ahead of the aircraft.
 - b. Two camera ports adaptable for (a) 9 1/2" format aerial cameras, (b) four coordinated 70 mm format cameras, or (c) the thermal infrared scanner.
2. One four channel strip chart recorder with edge event marker - Texas Instruments Servo-Riter II.
3. One Mark 1G incoming radiation solameter with 180° field of view.
4. Three Pyranometer radiometers - Talley Industries special reflectance solameters with 20°, 40°, or 60° fields of view.
5. One Portable Radiation Thermometer, Barnes PRT-5.

6. One thermal infrared scanner including the following:
 - a. InSb and tri-metal detectors, interchangeable and filtered to 4.5-5.5 microns and 8.7 to 11.5 microns respectively.
 - b. Two black body calibrators for high and low temperature references at the scan head.
 - c. One Tektronix 323 monitor oscilloscope.
 - d. Two seven-channel, wide-band Lockheed instrumentation tape recorders.
7. Five 70 mm Hasselblad 500 EL, 50 mm focal length cameras - four of which are clustered in a common frame with simultaneous triggering. Film-filter combinations are interchangeable and adaptable to experiment.
8. One 9 1/2" format, Fairchild K-17B, 12 inch focal length camera.
9. One 9 1/2" format, Fairchild K-17B, 6 inch focal length camera.

Ground Data Collection Equipment

1. One Epply Precision Spectral Pyranometer.
2. Two Mark 16 incoming radiation solameters with 180° field of view.
3. Six Pyranometer radiometers - Talley Industries special reflectance solameters with 20°, 40°, or 60° field of view.
4. One Troxler Neutron Probe and Ratemeter.
5. One ISCO Model SR Spectroradiometer.
6. One ISCO Model SRR Spectroradiometer recorder.
7. Six 35 mm Nikormat FTN cameras with 50 mm lenses.
8. One Digitrend Model 210 100 point, multifunction, automatic datalogger with computer compatible output punched paper tape and digital date/time annotation.
9. One 35 mm Minolta SRT101 camera with Rokker Fisheye lens.

10. Two Exotech Radiometers. Battery operated and filtered to measure radiation in the four Landsat bands. These can also be used for aerial data collection from the aircraft.

Photographic Laboratory Equipment

1. One Macbeth Quantalog Sensitometer.
2. One Macbeth Delta-log Photographic Color Analyzer NB-500P.
3. One Durst Laborator S-45 Special Enlarger with Condenser Light Source and Schneider Componon 80 mm and 150 mm Lenses.
4. One Durst L-184 Enlarger with Durst ACS403 Color Head Light Source and Schneider Componon 80 mm, 150 mm and 300 mm Lenses.
5. One Morse A11B Contact Printer for Color or Black and White Printing, 10" x 18" Printing Area.
6. One Morse A14A Contact Printer for Color or Black and White Printing, 10" x 10" Printing Area.
7. Two Morse B-5A 9 1/2" x 250' Rewind Film Processors.
8. One Lektra Gaseous Burst Film Processing Unit.
9. One Metorette 110 Color Film and Paper Processor.
10. One Metotemp 1 Temperature Control 9 Tank System.
11. One Meteor Standard H Print Dyer 26".
12. One GAS Transflo 1207 Black and White Film Dry to Dry Processor.
13. One Pako Temprow Dryer Model 400 for RC Papers.
14. One Kreonite 40-24 PWR Film and Print Washer.
15. One Arkay 1620-A Print Washer.
16. One Arkay 9 Tank 1 Gallon Size Film and Paper Processing Unit.
17. One Pako Pakomix 5 Chemical Mixer.
18. One Lighting Model L Chemical Mixer.
19. One Lektra Model TM-8 Decade Interval Electronic Timer.

20. One Treck Solid State Electronic Decade Interval Timer Model T-88.
21. One EP01 Electronic Decade Interval Time Model VST-1000.
22. One DuPont Cromalin Toning Console.
23. One DuPont Cromalin 4/C Laminator II.
24. One NuArc Model FT40LC, 30" x 40" Flip/Top Platemaker.
25. One NuArc Model CP25 Contact Printing Lamp with Point Light Source.
26. One Eastman Kodak Ektamatic Black and White Print Processor.
27. One Eastman Kodak Recordak Micro-File Unit MDC-2 Camera and MDR-2 Meter and Stand.
28. One Eastman Kodak Recordak Lodestar Reader and PES-1 Printer.
29. One Eastman Kodak Recordak Microfilm Splicer 5A.
30. Six 35 mm Nikormat FTN Cameras with 50 mm Lenses.
31. One 35 mm Minolta SR-T 101 Camera with 16 mm Fish Eye Lens.
32. One Nikkor Auto mm F-2.8 Lens.
33. One Nikkor Auto 105 mm F-2.5 Lens.
34. One 4" x 5" Crown Graphic Camera with 135 mm Lens.
35. One Eastman Kodak Image Control Keyboard IC-4.
36. One Eastman Kodak Four Light Copystand.
37. Aristo Trans-Lumintor Model T-22 Grid Lamp Light Source.
38. One Brunning Model 110 Diazo Printer-Processor.
39. One Honeywell Repronar Model 805A 35 mm Film Copier.
40. One Vivitar 85-205 mm Macro Zoom Lens (Nikon mount).
41. One Vivitar 2x tele-converter (Nikon mount).
42. One Vivitar 3x tele-converter (Nikon mount).
43. One NuArc VIC1418SL process copy camera.

Imagery Analysis and Interpretation Equipment

1. One Macbeth Model RD219 digital reflectance densitometer.
2. Two Macbeth Model TD404 digital displaying transmission densitometers.

3. Two light tables, Richards, Model GFL-918X.
4. Three type A1 light tables.
5. One stereo-scope, Bausch-Lomb Stereo 70 with light table.
6. Two FMA Multi-Format Photo Interpretation light tables.
7. Two I²S Brief-lite portable light tables, Model 10.
8. One Numonics Corporation electronic digitizer, Model 1224.
9. One I²S Mini-Addcol viewer with 9 1/2-inch and 70 mm film holder on projection capability, Model 6040-P.

The SADE system was developed interactively by Remote Sensing Institute of South Dakota State University and the Dicommed Corporation of Minneapolis, Minnesota, with the specific objectives of analyzing and managing remote sensing data. The system is interfaced with the University's IBM 370/145 computer and represents a medium-cost, state-of-the-art data analysis system with highly flexible modular design.

The South Dakota State University Computer Center Facilities include the following:

1. One IBM 370/145/ OS/V51.
2. Six 3340 disc drives.
3. Four 3420 tape drives.
4. One 1403 printer.
5. One 2540 read/punch.
6. One 3701 teleprocessor.
7. One 2701 data adapter.
8. One 2821 control unit, and
9. One 1627^{II} Calcomp drum plotter.

Also available at the center are standard card-data processing hardware, i.e., collators, sorters, punches, verifiers, and alphameric interpreter.

The SADE system configuration may be outlined by modules as follows:

1. Video monitor - The video monitor is a complete color densitometry system for analyzing the gray scale of back-lighted photographs in 32 colors. Color analysis is controlled by a pushbutton keyboard, and an electronic digital planimeter measures the relative areas of one or more color bands. The monitor consists of the following functional units:
 - a. A light box provides constant illumination for photographic transparencies. Continuously adjustable masks and a glass pressure plate accommodate all sizes of cut film up to 12 x 16 inches. A film transport is used for roll film.
 - b. A high-quality closed-circuit television camera is adjustable mounted on a vertical column above the light box so that it may be raised or lowered to accommodate both large and small photographs. The Camera Vidicon tube was selected for uniform response to the light intensity across the image. The camera lens has an adjustable aperture to accommodate photographs of different densities.
 - c. The density values of the photograph are represented by the analog value of the camera video signal and are displayed in color on the screen. A high-speed analog-to-digital converter continuously converts the video voltage levels to 32 discrete values. A special logarithmic amplifier makes each color band correspond to equal steps in the density of the photograph. Quantitative readings of brightness or density may be obtained by placing a calibrated photographic step wedge in the picture for reference.
2. Image Digitizing Unit - The image digitizer is configured to accommodate 35 mm, 70 mm, and 9 1/2 inch roll film with manual film translation and rotation. It scans a

57 x 57 mm area of positive or negative transparency, color, or black and white film. The digitizer has a density range of 0.05 to 2.45 density units. The image dissector tube (IDT), focusing lens, deflection system, and electronics are located in an optical assembly above the film plane. A hood shields extraneous light during the digitizing process. The film is held between a set of glass plates mounted on a large, flat, movable surface. A 350 watt tungsten Halogen lamp and condensing lens are mounted beneath the glass film holder in the cabinet along with the electronics and operator panel. A holder is provided for filters.

3. Data Conversion Unit - The Data Conversion Unit (DCU) contains the following hardware:
 - a. Fabri-Tek Memory.
 - b. Fabri-Tek Memory Power Supply.
 - c. Atron Controller (DFM) - The Atron Controller located in the DCU will perform the following functions:
 - (1) Sub-device communication service.
 - (2) HSM data and address update.
 - (3) D-57 to HSM image store and image interface.
 - (4) ATC to monitor HSM, image move down.
 - (5) 2701 to HSM, image move down and image move up.
 - (6) D-57 to 2701 (bypass).
 - (7) ATC to 2701 (bypass).
 - (8) Sub-device selection.

The Data Format Module is a sub-device of the Atron controller. Four types of large printed circuit cards are used in the DFM -- Read Only Memory (ROM), Read/Write Program (R/RPM), Microprocessor, and Input-output (I/O). Two (I/O) cards are used to provide

the four interface channels (two channels per I/O card) which supply all of the communications between the DFM and DCU. The DFM has no switches or indicators and is completely controlled by the signals it receives via the four interface channels. Channels one through four are interfaced to the D-57, 2701 local, HSM, and ATC respectively. When power is supplied to the DCU, the DFM is initialized and the microprocessor begins executing programs stored in the ROM. Twelve firmware programs stored in the ROM provide all of the operating modes for the DFM.

- d. Three Logic Decks
 - (1) Deck A - High Speed Memory (HSM) Interface
 - (2) Deck B
 - (a) - 2701 Local Interface.
 - (b) - Printer Interface.
 - (c) - TTY Interface.
 - (3) Deck C - Analog Tape Converter (ATC).
- e. Five Logic Power Supplies.
- f. One Control Panel.
- g. One Connector Panel.
- 4. Lockheed Recorder - The Lockheed 417 is a portable wideband magnetic tape recorder. Completely modularized, the Model 417 WB is capable of recording up to seven tracks of either FM or direct data on 7-inch reels of 1/2 inch instrumentation tape. As a reproducer, the 7-track unit can reproduce all seven tracks simultaneously or the user can interchange modules to set up any combination of eight record and reproduce functions. One reproduce track is arranged so that it may be switched to all seven tracks,

permitting the operator to monitor all tracks while recording. It operates at three speeds: 3 3/4, 15, or 30 ips.

5. Film Printer - The printer/viewer display unit is used either on or off-line to display and record analog data. The option of level slicing the data before it is displayed on CRT is available. Permanent record of the video information on the display unit is made by using a variable speed 70 mm continuous strip camera.
6. Teletype - The ASR-33 teletype is used for communication between the computer and the SADE equipment at RSI. Local and line modes can be used with off-line and on-line operations, respectively. Paper tape serves as an optional input/output medium.
7. Digital Tape Unit - A Dicomed D15 Digital Magnetic Tape Drive and interface microprocessor enables data conversions to digital domain or display generation to take place independent of the IBM facility.

The SADE system can be operated and utilized without benefit of computer interface or control (off-line). Typical off-line functions are:

1. Video monitor display of digitized film information.
2. Video monitor display of analog tape information.
3. Transmission of analog information to film printer.
4. Transmission of level-sliced analog information to film printer.
5. Level slicing of vidicon scans or image dissector scan.

With the benefit of computer interface and interactive control (on-line) SADE functions are exemplified by the following:

1. Transmission of teletype communications to and from computer.

2. Transmission of digitized image information to the computer.
3. Digitization and transmission of analog tape information to the computer.
4. Transmission of digital or analog tape data to the display monitor through the high speed memory.
5. Transmission of processed digital or analog tape information to the film printer.
6. Registration of images via the digitizer and display monitor.
7. Display of digital information on line printer.
8. Color separation digitizing.
9. Moving window dynamics of video information.

System interface software and IBM channel programs together with the on-line supervisory program for SADE are all relatively transparent to the image analysis process and, therefore, won't be discussed.

Symbol printing and overstrike shade printing routines are available for line printer interaction with digital images. The software for subscene extraction and sample point location from Landsat CCT's or SADE-generated, packed pixel CCT's exists and the NASA Digital Image Rectification System for Landsat CCT's are operational. Extracted sample pixels can be processed via standard statistical packages to derive interrelationships or ground truth correspondence. Operations might include correlation and regression -- both simple linear and multiple linear -- analysis of variance, and/or stepwise discriminant function analysis.

Image compositional analysis and automatic classification analyses might take one of several forms. An anomaly census, sizing and plotting routine relies primarily on local contrast and continuity decisions. A boundary detection routine relies on 2 dimensional spatial gradient operations to define demarcations between homogeneous objects. Adjacency classification extends boundary detection methods

to provide identification/mapping of spatially distinct objects. Traditional Fourier analysis and binary Fourier analysis in one or two dimensions can be employed for image decomposition, filtering, or feature generation in further classification analyses. Supervised and unsupervised, non-parametric pattern classifiers in n dimensions are operational. Processed or unprocessed images can be transformed, enhanced, enlarged, reduced, and/or alphanumerically annotated on SADE. Data distribution and plotting programs assist application decisions for these processes. Whether automatically classified or interpretively extracted, thematic data sets can be stored, interpreted, overlaid, tabulated, and plotted via an information extraction/mapping software system. Calcomp based drum plotting programs enable line mapping, image scan line plotting, and data point scatter plotting.